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ANNUAL REPORT OF RESEARCH AND TECHNOLOGIC WORK ON COAL

FISCAL YEAR 1944

BY

A. C. FIELDNER, P. L. FISHER, AND R. E. BREWER

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

ANNUAL REPORT OF RESEARCH AND TECHNOLOGIC WORK ON COAL

Fiscal Year 1944[1]

By A. C. Fieldner,[2] P. L. Fisher,[3] and R. E. Brewer[4]

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1/ The Bureau of Mines will welcome reprinting of this paper, provided the following acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7322."

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INTRODUCTION

The past full year of war has increased greatly the demand for virtually all kinds of fuel, and the Bureau of Mines research and service facilities have been extended to meet these unprecedented requirements.5/ Liquid fuels, such as aviation and motor gasolines, are fundamental to modern warfare. Bituminous coal and anthracite are needed, not only to serve the expanded industrial program for which coal normally is used but also to replace natural gas, wherever possible, and fuel oil in the Eastern States, New England, and the Pacific Northwest. Railroad transportation with energy derived from coal is replacing much of the motor-vehicle transportation that has been stopped or curtailed to conserve rubber. Pulverized coal has been found to be a satisfactory and cheaper substitute for fuel oil in metallurgical heating furnaces. Colloidal fuel - a mixture of coal dust and oil - may offer a partial substitution for certain coal-burning equipment. Several industrial experiments have been made with this type of fuel. The expansion of the steel industry in connection with the war program has required a corresponding increase in the production of metallurgical coke and its associated byproducts - light oil, tar, ammonium sulfate, and surplus gas. If the war is of long duration and new reserves of petroleum are not discovered, wartime trends from fuel oil to coal probably will not be reversed.

Regular inspection service was maintained for Federal agencies, with a large increase in analytical and testing work on coal samples from many sections of the country. Consulting service was rendered the Government and industry on types and changes in equipment, developing substitute fuels to meet present shortages, and recommending methods for increasing the efficiency of power-plant operation. At the request of the War Department, the Bureau has conducted a program of coal sampling and training of Army personnel in sampling at Army posts. Work on boiler feedwater was tripled over 1943 to protect the vital boiler plants in the numerous camps established.

Coal areas were explored to determine minable deposits that could be developed as additional sources of coking coal, to relieve the present critical fuel situation, and to provide a continued supply of coal in the peace era to follow. Mining practices were improved in the interest of efficiency, conservation, and safety. The inflammability and explosibility of powdered metals, military pyrotechnics, and materials used in and produced by the plastics industry received concentrated attention. The possibilities of increasing the charges of permissible explosives in coal blasting were studied.

Improvements in methods of preparation and cleaning have yielded coals of higher quality and resulted in the conversion of coals, formerly rejected as waste, into usable fuel. Methods have been developed for safely storing coal at isolated Army posts and other places far removed from the source of supply. Combustion studies have been pointed toward preventing serious loss

5/ Fieldner, A. C., Recent Developments in Fuel Supply and Demand: Jour. West. Soc. Eng., vol. 48, part 1, February 1943, pp. 127-147; Bureau of Mines Inf. Circ. 7261, 1943, 27 pp; abs. Chem. and Eng. News, vol. 21, July, 1943, p. 1067.

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of steaming capacity from the external corrosion of furnace-wall tubes. An investigation has been conducted on the satisfactory utilization of small sizes of anthracite for domestic fuel. To maintain supplies of suitable coking coals needed by industry, carbonization tests were completed on several additional coals of the United States. The Coke Production Survey has made contact with the entire coke industry, and technical assistance has been rendered operators in the production of better blast-furnace fuel.

A small pilot plant for gasifying subbituminous coal and lignite was successfully operated in 1944. It was found that this method can be effectively employed to produce gas for the reduction of iron ore and for the synthesis of oil or gasoline from coal. A larger pilot plant for the production of 500,000 cubic feet of gas per day is under construction at Grand Forks, N. D.

On April 5, 1944, the Congress passed an act (Public Law 290, 78th Congress) authorizing the Bureau of Mines to construct and operate demonstration plants to produce synthetic liquid fuels from coal, oil shales, agricultural and forestry products, and other substances, in order to aid the prosecution of the war, to conserve and increase the oil resources of the Nation, and for other purposes. Further development work was completed in the laboratory-size plant at Pittsburgh, Pa., in the production of fuel oil and gasoline from coal. In the synthesis of liquid fuels from hydrogen and carbon monoxide, methods for the preparation of active iron catalysts were investigated, and engineering tests were made on new procedures for rapidly removing the heat of the reaction.

The present report is the ninth in a series of annual reports of research and technologic work on coal and covers the period from July 1, 1943, to June 30, 1944. References are given to publications of the Bureau that cover these investigations more completely. Much of the Bureau's work remains confidential, and details cannot be disclosed during the national emergency; but they will be made available to both industry and consumers when war restrictions are removed.

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This report includes work done under the technical direction of the following members of the staff of the Bureau of Mines:

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ORIGIN, COMPOSITION, AND PROPERTIES OF COAL

Inspection, Sampling, and Analysis

At the request of the War Department, the Fuel Inspection Section instituted a sampling program for coals delivered at Army posts and instructe Army personnel in proper methods of sampling. In all, 2,154 visits were made to Army posts, and 1,544 samples were collected. To assist the Solid Fuels Administration for War in improving the quality of anthracitic coal as shipped, to save manpower and transportation facilities, and to improve burning efficiency, 252 visits were made to 125 breakers and 985 samples were collected. For the general use of the Government in making coal purchases and for public information, 668 samples of bituminous coal were collected in 9 States - 6 from California, 144 from Colorado, 20 from Kentucky, 3 from Maryland, 92 from New Mexico, 138 from Ohio, 4 from Oregon 42 from Pennsylvania, and 219 from West Virginia. Coal purchases by Federa agencies during the fiscal year 1944 amounted to approximately 11,500,000 tons. In connection with contracts for furnishing this coal, 9,005 reports of coal analyses were issued to Federal agencies. To assist research sections of the Bureau in finding coals suitable for the use of war industries in certain localities, 68 samples were collected for carbonization tests, 16 for hydrogenation assays, and 5 for oxidation and spontaneous heating studies. The carbonization samples represented 3 from California, 49 from Colorado, and 16 from New Mexico. The coals for hydrogenation included 6 column samples for microscopic studies and 10 face samples from western Kentucky for analysis. For studies of oxidizing and spontaneous heating characteristics of coal 1 sample was collected in Colorado, 2 in western Kentucky, and 2 in New Mexico.

In connection with the inspection of coal purchased by Federal agencie the Coal Analysis Section analyzed 6,532 samples, more than 80 percent for posts and stations of the War and Navy Departments and for the Solid Fuels Administration for War. In addition, 3,381 samples were analyzed for

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rrelation with researches by various sections of the Bureau of Mines and ther Government agencies on the utilization of coal by carbonization, mbustion, and liquefaction, and in studies of special properties, such s the explosibility of coal dust.

Federal coal-mine inspectors submitted 10,704 samples of dusts taken om the ribs, roofs, and floors in 1,304 of the larger commercial mines 23 states. The analyses of these dusts gave data for determining the sceptibility of these mines to dust explosions and for formulating recom-ndations to appropriate mine operators concerning possible hazards.

ndamentals of Coal Sampling

A recent investigation[6] on the principles governing the establishment rigorous specifications for the sampling of coal showed that mathematical obability could be applied and that the fundamental variables of ash stribution in coal could be studied by similar methods. Knowing the riability in ash content of increments of a specified weight of coal, it s found that their number can be computed to yield a sample of pre-signed accuracy. Mathematical developments were made to cover both ndom sampling and increments taken in an orderly way over the entire lot coal sampled.

alyses of Kentucky Coals

A compilation[7] of analyses of Kentucky coals made by the Bureau of nes was published as the second paper on Kentucky coal and is another in e series of papers describing coals of individual producing States. The ology of the western and eastern coal fields, methods of mining and prepa-tion, economics of production, distribution, uses, and the relationship mine samples to commercial shipments are discussed. Descriptions of mine, pple, and delivered samples include chemical analyses, calorific values, assification by rank, agglomerating index, fusibility of ash, true specific avity, sulfur forms, thickness of beds, nature of floor and roof, and rtings in the bed. Kentucky ranked fourth in coal production in the ited States for 1922 to 1941, except for the 2 years 1927 and 1932, when was in third place.

6/ Landry, B. A., Fundamentals of Coal Sampling: Bureau of Mines Bull. 454, 1944, 127 pp.

7/ Fieldner, A. C., McFarlan, A. C., Toenges, A. L., Maize, E. R., Fraser, T., Crentz, W. L., Anderson, R. L., Bell, C. H., Snyder, N. H. Cooper, H. M., Abernethy, R. F., Tarpley, E. C., Swingle, R. J., and Hartner, F. E., Analyses of Kentucky Coals: Bureau of Mines Tech. Paper 652, 1944, 323 pp.

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A paper[8] giving analyses and similar descriptions of Virginia coals as indicated in the preceeding paragraph for Kentucky coals was published. Original reserves of anthracitic (semianthracite) coal in Virginia have been estimated as 500 billion net tons and those of bituminous coal as 21,149 billion net tons. Production of semianthracite and bituminous coal in 1941 amounted to 18,441,000 tons from 155 mines of commercial size.

Analyses of Pennsylvania Anthracitic Coals

A publication[9] describing mine, breaker, and delivered samples and showing their analyses, with brief descriptions of the anthracite fields of Pennsylvania, methods of mining and preparation, and important economic data on the industry was issued. At the close of 1942 the estimated reserve was 14,431,250,000 long tons in the four main Pennsylvania anthracite districts. Production in 1942 for the entire State totaled 69,327,729 net tons.

Constitution, Analytical Methods, and Standardization

The Coal Constitution Laboratory has investigated the constitution of a number of coals whose mining, carbonization, and liquefaction properties are being studied by other sections of the Bureau of Mines. Core-drill samples from exploration projects in Wyoming, Colorado, Nevada, Oregon, and Alabama were examined, and measurements and locations of different kinds of material in the drill column were recorded. After separation of the coal cores and associated rock, samples of the cores were prepared for proximate and ultimate analyses, agglutinating-value tests, and microscopic examination. The procedures of petrographic analysis were studied with particular reference to coordination of megascopic and microscopic methods of petrologic integration. A number of coals were investigated to determine the relation of their petrographic composition to special chemical and physical characteristics.

An electron microscope was installed late in the fiscal year at the Central Experiment Station, Pittsburgh, Pa. It is hoped that with this new tool of research many of the baffling problems encountered in coal research may be explained, particularly from observations of the detailed structure of material made at high magnification.

Miscellaneous analytical work for various sections of the Bureau of Mines included analyses of 486 samples of coal and miscellaneous materials

8/ Fieldner, A. C., Eby, J. B., Campbell, M. R., Toenges, A. L., Fraser, Crentz, W. L., Anderson, R. L., Bell, C. H., Snyder, N. H., Cooper, M., Abernethy, R. F., Tarpley, E. C., and Swingle, R. J., Analyses of Virginia Coals: Bureau of Mines Tech. Paper 656, 1944, 159 pp.

9/ Fieldner, A. C., Ashley, G. H., Toenges, A. L., McElroy, G. E., van Siclen, M., Buch, J. W., Snyder, N. H., Cooper, H. M., Abernethy, R. F., Tarpley, E. C., and Swingle, R. J., Analyses of Pennsylvania Anthracitic Coals: Bureau of Mines Tech. Paper 659, 1944, 271 pp.

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hese analyses included determinations of the agglutinating value and gas- nd coke-making properties of coals; the composition of boiler-water com- ounds, boiler scales, sludges, deposits, and rock dusts; the percentages f phosphine in acetylene generated from calcium carbide; and chemical nalyses of coal-ash slags and slag deposits, clays, coal savers, shales, nd other miscellaneous materials.

In connection with the survey of the coking properties of American coals, mall-scale laboratory carbonization tests were made of coals of the United tates and Alaska to determine their suitability for the production of coke r char. These tests included the Fischer low-temperature carbonization ssay, the U. S. Steel Corporation high-temperature distillation test, and he Bureau of Mines agglutinating-value test. Results of these tests on everal coals were incorporated in publications cited later. (See Carbon- zation and Gasification, p. 41.)

The agglutinating-value test has proved valuable for measuring the xtent of oxidation of stored coal compared with fresh coal, in studies of he storing qualities of coals now in use, and of coals from new sources ow being explored.

Construction of new blast furnaces in the West for the production of teel has created a demand for western coals of satisfactory coking quality. mall-scale coking and agglutinating-value tests have been useful to coke- ven operators and other users of western coals.

are and Uncommon Chemical Elements in Coal

A review summarizing available published information concerning the ccurrence of rare and uncommon chemical elements in coals of the United tates and other countries was prepared.10/ Although more than half of the nown elements have been reported as occurring in coal, the percentages are pparently too low to warrant their industrial recovery. Flue dusts from ertain gas works in England are potential sources of germanium and gallium.

ields of Primary Tar and Light Oil from Coals of rious Ranks and Types

A method was developed for predicting low-temperature yields of primary ar and light oil from chemical analyses of coals of various ranks and ypes.11/ The combined percentage of tar and light oil was found to equal $.697X + 0.0031X^2 - 6.4$, where X equals the volatile matter minus 1.3 times he oxygen. Equations relating tar and light-oil yields with the hydrogen ontents of common banded (bright), splint, and cannel coals were derived. hese linear equations have two constants whose values differ slightly for oals of different types.

0/ Gibson, F. H., and Selvig, W. A., Rare and Uncommon Chemical Elements in Coal: Bureau of Mines Tech. Paper 669, 1944, 23 pp.

1/ Odo, W. H., and Selvig, W. A., Low-Temperature Distillation Yields of Primary Tar and Light Oil from Coals of Various Ranks and Types: Bureau of Mines Rept. of Investigations 3748, 1944, 10 pp.

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Comparison of Standard Test Sieves

In analyzing and testing powdered materials there is frequent need of a ready means of comparing the data of sieve analyses as determined by one series of test sieves with those of a series more familiar to the user. To meet this need a tabular comparison and discussion of its significance were made of the fine-series, square-mesh-wire test sieves currently used in four different countries.12/ The sizes of openings, in millimeters, for the standard series of sieves used in Great Britain, the United States, Germany, and France were compared. The openings for all sieves, expressed on the same horizontal line of the table, are within the permissible variations of the average opening of the corresponding U. S. Standard sieve. The "mesh-number" designations commonly used are included in parentheses in the table. In a technical sense the work "mesh" is meaningless, unless the diameter of the wire size used in the sieve is also specified, so that the size of the opening can be determined. The use of the term "mesh" should be discouraged, unless the particular corresponding name of the sieve is stated; thus, U. S. Standard No. 35, or 500-micron, sieve.

Application of the Rosin-Rammler Law for Screening Coal

It is sometimes desirable to know what changes in sizing characteristics would appear in screened coals if screens of different-size openings than those employed had been used. A study was made of the application of the Rosin-Rammler law as a solution to this problem.13/

The equation for the Rosin-Rammler law is

$$R = 100e^{-\left(\frac{X}{\bar{X}}\right)^{n}},$$

where R is the "residue", or percentage of oversize after particles of diameter X and smaller are screened out. $\bar{X}$ and n are constants (for a given coal), and e is the base of the Napierian logarithms. The law appears to describe satisfactorily the size distribution in coals. The validity of the law is discussed and calculations to compute the "missing sizes" in coal are shown. This general subject is also discussed by Bertrand A. Landry.14/

12/ Brewer, R. E., Comparison of Fine-Series, Square-Mesh-Wire Test Sieves of Different Countries: Bureau of Mines Rept. of Investigations 3700, 1944, 5 pp.

13/ Scott, G. S., Application of the Rosin-Rammler Law to the "Missing Sizes" in Screened Coal: Bureau of Mines Rept. of Investigations 3773, 1943, 9 pp.

14/ Landry, B. A., See footnote 6, p. 5.

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Precision of the Volatile Matter Determination

A statistical study[15] dealing with errors of analysis in the volatile-matter determination for anthracite, low-temperature coke, and subbituminous coal was made at the request of Committee D-5 on Coal and Coke of the American Society for Testing Materials. The investigation was based on duplicate determinations of 100 samples of each of these three materials and showed that the present A.S.T.M. permissible differences of 0.2, 0.2, and 0.5 percent, respectively, were too stringent. It was recommended that the A.S.T.M. permissible differences between duplicate determinations of volatile matter by the same laboratory be revised to permit 0.3 percent for anthracite, 0.5 percent for low-temperature coke, and 0.7 percent for subbituminous coal.

Standardization of Proximate Analysis

Points of difference in the standard procedures of the British Standards Institution and of the American Society for Testing Materials for determining volatile matter in coal were discussed.[16] The latter method, which is used by the Bureau of Mines, specifies a temperature of 950° C., compared with 925° C., as specified by the British standard. In the United States little use is made of the "air-dried" analysis in comparing coals, because the lower-rank coals, which contain relatively large quantities of bed moisture, would be unduly favored.

Cooperative Investigation on Fusibility of Coal Ash

A cooperative investigation by 16 participating laboratories in the United States and Canada showed that furnace atmosphere is the most important factor in the ash fusion determination.[17] These laboratories, using 5 types of gas- and 2 types of electric-furnaces with 5 kinds of atmospheres, provided 23 furnace-type and furnace-atmosphere combinations. Results obtained were within the permissible tolerances of A.S.T.M. method D271-40 for the coal-ash samples tested. In general, softening temperatures observed with natural gas were higher than those with the manufactured gas or the gas of constant composition which was used in the electric furnace.

COAL MINING

Experimental Mine and Dust Explosions

Studies of Coal-Mine Roof

The mechanical properties and behavior of roof rocks in the Midland mine of the Pittsburgh Coal Co. were studied to determine the causes of the partial

15/ Selvig, W. A., Precision of the Volatile-Matter Determination for Anthracite, Low-Temperature Coke, and Subbituminous Coal: Bureau of Mines Rept. of Investigations 3739, 1943, 6 pp.

16/ Fieldner, A. C., and Selvig, W. A., Discussion of "The Proximate Analysis of Coal" by Joseph Brown and Alan S. Bean: Jour. Inst. Fuel, vol. 16, August 1943, p. 182.

17/ Cooper, H. M., and Abernethy, R. F., Cooperative Investigation of the Effect of Furnace Type and Atmosphere on Fusibility of Coal Ash: Bureau of Mines Rept. of Investigations 3724, 1943, 43 pp.

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failure of an asphalt paint coating previously applied to the roof of this mine.[18] The investigation was one part of a study of mine roof being conducted by the Committee on Roof Action of the American Mining Congress. Portions of the sealing material with some of the roof rock, to which it was originally attached, fell in numerous places. It was concluded that the partial failure of the coating to remain on the roof surfaces resulted primarily from the nonuniform composition of the roof rock itself.

Application of Rock Dust in Coal Mines

Successful automatic devices for placing rock dust close to working faces in mechanized coal mines are greatly needed. Tests were made of a recent device which consisted of a wire-mesh basket containing rock dust and provided with a drop bottom. The results showed that the dust was effectively discharged through the drop bottom by the force of pressure waves in advance of the flame of a coal-dust explosion. A review[19] was prepared showing the slow progress in rock dusting during the past 5 years. Examination of reports of 57 dust explosions in mines over the 5-year peri ended June 30, 1943, showed that no rock dust had been used in the area traversed by flame in 32 explosions that resulted in 344 deaths and 95 nonfatal injuries. In 9 instances in which rock dusting was unquestionably inadequate, 287 deaths resulted. In the remaining 16 explosions, rock dust played an important part in stopping the explosion. In these 16 explo sions, 32 persons died. In 4 others the use of rock dust was apparently the sole cause of stoppage of explosions. Data obtained in some 1,800 explosion tests in the Bureau of Mines Experimental coal mine have provide the fundamentals upon which dust explosions in coal mines could be greatly reduced, if effectively put into practice.

Increase in Charge Limit of Permissible Explosives

To meet the problem created by use of mining machines having cutter b up to 10 feet in length, the Coal Mining Institute of America requested th the quantity limit for permissible explosives be raised from 1.5 to 3 pou so that heavier blasting can be practiced. The regular testing gallery fo explosives was not equipped for numerous tests with 3-pound charges, nor could equipment suitable for testing such large charges under coal-mine co ditions be readily procured. To obtain immediate information, a program o tests in the Experimental Coal Mine was devised and developed. The first 68 tests were limited to determinations of conditions under which a 3-pound charge of a permissible explosive could ignite a gas-air mixture (8 t 9 percent natural gas) placed in front of the face from which the shot is fired. The mixture did not ignite easily, so that closer control of numer variables had to be made.

18/ Greenwald, H. P., Mine Roof Sealing to Prevent Slate Falls: Min. Con Jour., vol. 30, March 1944, pp. 53-55.

19/ Greenwald, H. P., Statistics Show Rock-Dusting Gains Slowly in Americ Coal Mines: Min. and Met., vol. 25, Feb., 1944, pp. 98-99; also und title, Use of Rock Dust to Prevent Dust Explosions in Coal Mines, 1938-43: Trans. Am. Inst. Min. and Met. Eng., Coal Div., vol. 157, 1944, pp. 116-123.

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In the first series of tests all boreholes were 2-1/4 inches in diameter and 6 feet in depth, with a gelatin-type permissible explosive placed at the rear of the hole and a No. 6 detonator at the rear of the charge. The same explosive was used in all tests and represented one of the more dangerous of the permissible types. In each test a minimum volume of about 900 cubic feet of the gas-air mixture surrounded the free face or faces of the coal. The probability of ignition in five tests was determined for each set of conditions. Thus, if there were two ignitions and three nonignitions of the gas, the probability was 0.4. The first determinations were with the explosive unstemmed and packed solidly in the hole, a loading condition called "density 1." Under these conditions 1 pound of explosive gave probability 0.0, 3.5 pounds, 0.4, 8 pounds, 1.0, and 13 pounds, 0.2. Thus, at the point of maximum danger with 8 pounds of explosive, at least 2.5 times the proposed 3-pound charge limit was used. It was next determined that stemming an 8-pound charge of explosive with 1 pound of fire clay reduced the probability of ignition from 1.0 to 0.0. The stemming occupied about 3 inches of the borehole.

In a second series of tests 6 inches of coal separated the explosive and gas-air mixture. Thirty tests have been made without a resulting ignition, indicating that the likelihood of igniting gas because of weak or fissured walls of the borehole is small. However, more correlations between results of the two series of tests are needed before the probability of ignition can be known when undisturbed coal lies between the explosive and gas-air mixture.

Explosibility of North Dakota Lignite Dust in Air

To supply information on the explosibility of lignite dust, a study was made of conditions in a North Dakota lignite mine, and samples were collected for analysis and for tests in the Experimental coal mine. Tests of dust of the size found in this mine showed that a self-sustained dust explosion could not be produced when ignited by a blown-out shot of 4 pounds of black blasting powder. When the source of ignition was a strong gas explosion, a self-sustained dust explosion developed at once; this was prevented only when the incombustible content of the dust was raised to 60 percent. When the moisture content of the lignite was reduced to 20 percent, a self-sustained dust explosion developed from a blown-out shot of 4 pounds of black blasting powder. The explosion was prevented by increasing the total incombustible to 40 percent. When the source of ignition was a gas explosion, 60 percent of total incombustible was required to prevent self-sustained explosions. Lignite dust containing 20 percent moisture could be ignited by electric arcs and the flame of detonating dynamite but less readily than low-moisture, high-volatile coals.

Inflammability and Explosibility of Industrial Dusts

As part of a program designed to promote safety in industrial operations, the Bureau of Mines has investigated the explosion hazards of numerous dusts and powdered products. Requests from industries and Government agencies on the explosion hazards of various dusts continued steadily, and 69 samples were received during the year. The samples submitted included dusts of metals,

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resins, pitch, components of explosives, and agricultural products. A number of requests for information concerned explosion hazards that might be present when airplane-engine pistons are cleaned by a blast of carbonaceous materials, such as cracked wheat or clover seed dust. Other requests were for information on the hazards of dusts that collect in exhaust dusts from vehicular tunnels and of dusts of dried organic materials produced during the complete dehydration of vegetables and other foods.

Explosibility of Powders from the Plastics Industry

A study was made of the inflammability and explosibility of powders used in or produced by the plastics industry.[20] Data from this study were required in formulating a safety code[21] for the prevention of explosions and for safer production and handling of powders from plastics in industry. Fifty-seven powder samples, comprising 31 resins, 15 molding compounds, 4 synthetic resin ingredients, and 7 fillers for molding compounds, were tested in the dust-explosions laboratory. Tests included determinations of the minimum ignition temperature and minimum energy needed for ignition of dust clouds, relative inflammability with two different sources of ignition, minimum concentration required in a dispersion of dust in air to permit ignition and flame propagation, maximum pressure and rate of pressure rise developed in small explosions, and reduction in oxygen content of air necessary to prevent ignition. Test results were obtained on powders of two sizes of fineness, namely, as-received and minus 200-mesh. Comparative data show that the explosibility of fine sizes of many powders from plastics is only slightly lower than that of most inflammable metal powders and that the potential dust-explosion hazard in the manufacture of certain plastics is greater than that of more common carbonaceous dusts.

Precision Measurements of Minimum Static Electric Sparks

A discussion of the importance of fundamental studies on static electric phenomena, a description of precision apparatus for such studies, and a statement of results obtained with various explosive mixtures are contained in a recent publication.[22] In figure 1 are 2 curves for benzene-air mixtures on the left and two curves for natural-gas-air mixtures on the right. The lower benzene-air-mixture curve shows the energy required to ignite mixtures containing 2 to 6 percent benzene with 0.05-inch sparks between 1/8-inch spheres. The upper curve represents data obtained with 1/2-inch spheres also spaced 0.05 inch apart. These curves indicate qualitatively that the smaller the effective cooling area of the electrodes, the lower the minimum ignition energy required to start a self-propagating chemical

20/ Hartmann, O., and Nagy, J., Inflammability and Explosibility of Powders Used in the Plastics Industry: Bureau of Mines Rept. of Investigations 3751, 1944, 38 pp.

21/ Committee on Dust Explosion Hazards, Division I, Subcommittee for the Prevention of Dust Explosions in the Plastics Industry, National Fire Protective Association. Code for the Prevention of Dust Explosions in the Plastics Industry: Nat. Fire Protec. Assoc. Quarterly, vol. 37, Part 2, April 1944, pp. 4-20.

22/ Guest, P. G., Apparatus for Determining Minimum Energies for Electric Spark Ignition of Flammable Gases and Vapors: Bureau of Mines Rept. of Investigations 3753, 1944, 16 pp.

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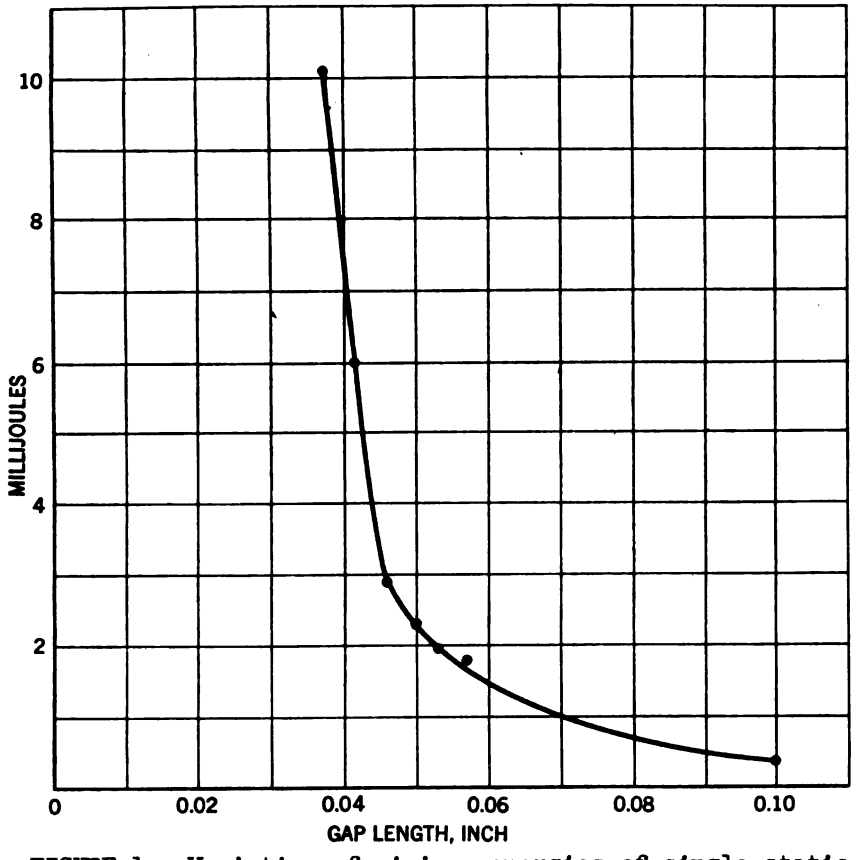

FIGURE 1.- Variation of minimum energies of single static sparks for ignition of mixtures of varying composition, using fixed spark gaps.

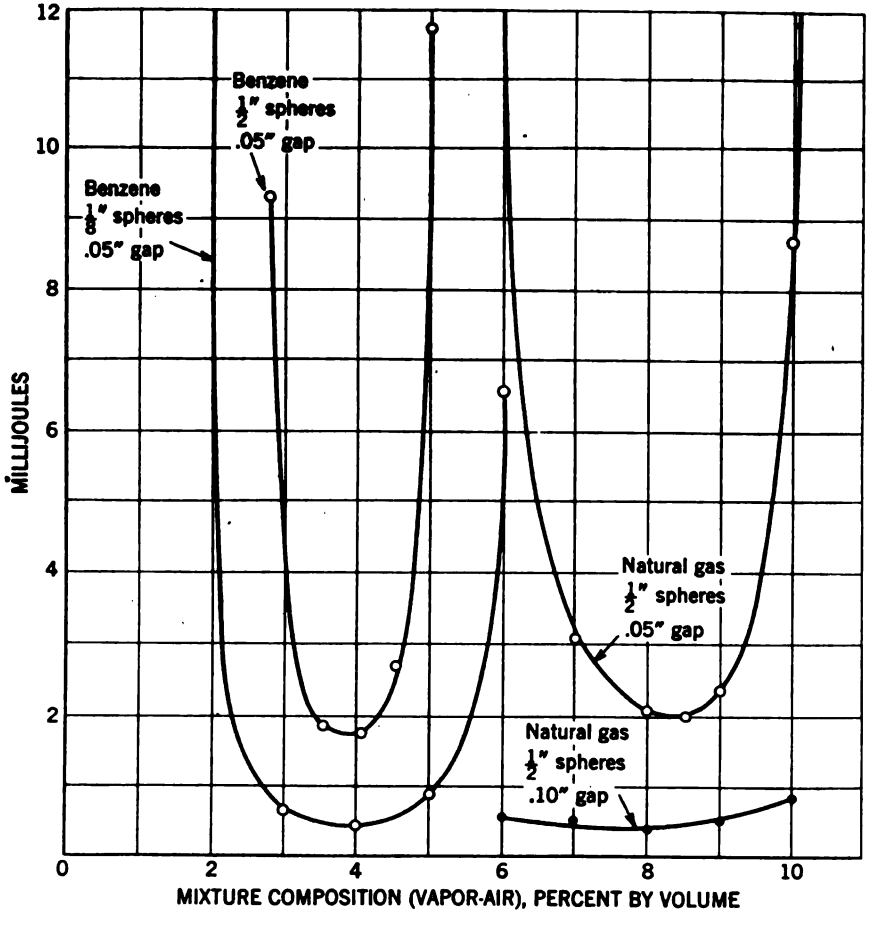

FIGURE 2.- Variation of minimum energies of single static sparks for ignition of mixtures of 8 percent natural gas, using $\frac{1}{2}$-inch spheres and varying spark gaps.

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reaction. The upper and lower curves for natural-gas-air mixtures were obtained by using 1/2-inch spherical electrodes, spaced 0.05 inch and 0.10 inch, respectively. The electrode cooling effect is seen here also, since, as the gap and hence the zone of initial activation is increased, the energy required for ignition is reduced.

The relationship between ignition energy and length of spark is represented better in figure 2, which shows the data obtained with 1/2-inch sphere electrodes in mixtures of identical composition. It seems likely that the rather abrupt change in slope, as the spark gap is made shorter than 0.05 inch, is due to a shift in the locus of flame inception from the path of the discharge to an annular region surrounding it. Both the benzene and the natural-gas curves show the well-known variation of ease of ignition with mixture composition. The benzene-air mixture most susceptible to spark ignition is somewhat richer than the most perfectly combustible mixture which contains 2.71 percent C_6H_6, while the most sensitive natural-gas-air mixture is on the lean side. It can be seen that ignition of mixtures near the upper and lower limits for flame propagation (1.41 to 6.75 percent for benzene and 4.75 to 13.8 percent average for Pittsburgh natural gas) requires comparatively high energy when sparks shorter than 0.05-inch occur between electrodes 1/2 inch or larger in diameter.

A critical review of the literature dealing with the electrical conductivity of solid dielectrics was made.23/ Methods of removing static charges are described, methods and conditions for the measurement of resistivity are discussed, and equations for the calculation of resistivity are given. In addition to fundamental laboratory research on static electric phenomena, such as the resistivity of various dielectrics at different humidities, data were obtained on the energy of static sparks that may be drawn by the human body in contact with charged surfaces, such as blankets and sheets in hospital operating rooms and from handling materials in munitions plants.

Mining Methods and Practices

Improvements in coal-mining practices in the interest of safety, efficiency, and conservation have resulted in increased production of coal this year. Mining practices were studied, particularly in the steeply dipping mines of the Roslyn and Pierce County fields of Washington, in the Monarch mine at Sheridan, Wyo., and in coal-stripping operations in Ohio, Pennsylvania, and West Virginia.

Pillar Extraction

A plan of pillar extraction in the Monarch mine in Wyoming was developed that would result in an increased recovery of 36 percent of coal at an additional cost of $0.07 per ton. This increased cost probably can be offset by the decrease in capital charges per ton resulting from increased production from a section of the mine.

23/ Cohn, E. M., and Guest, P. G., Influence of Humidity Upon the Resistivity of Solid Dielectrics and Upon the Dissipation of Static Electricity: Bureau of Mines Inf. Circ. 7286, 1944, 41 pp.

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Coal Strip Mining

Reduction in highway, airport, and drainage construction, as a result of the war, has made more earth-moving equipment available, and many contractors have entered the coal-stripping fields. Carry-alls and other light equipment are easily transported and appear to be successful in hillside-stripping operations in mountainous country. Increase in the use of such equipment has resulted in increased production of badly needed coal

Control of Sulfur and Ash in Mine-Run Metallurgical Coal

As a requisite for suitable coke, emphasis has always been placed on low sulfur and ash content in the coal, so that the resulting coke would also be low in these impurities. However, uniformity of the sulfur and ash content of coke for blast-furnace use is also very important, both for efficient operation of the furnace and for increased production of pig iron for war. Bureau of Mines engineers studied the mining methods and practices of sampling, selective mining, grading, underground and surface blending, and surface preparation as followed at five representative mines. The results obtained at these mines have been summarized.24/ This study showed that, at certain mines, part of the minable coal area or part of the coal bed produced unsatisfactory metallurgical coal, but when this coal is graded and blended with coal having a smaller percentage of impurities from other parts of the same mine, a satisfactory metallurgical coal is obtained. It is hoped that by the introduction at other mines of some of the practices at the mines studied, additional coal may be made available for metallurgical purposes that otherwise could not be used because of wide variation of sulfur and ash content. The plan has been recommended by the Coke Production Committee, which has been functioning at the suggestion of the Solid Fuels Administration for War. Interest of coal industrialists in this subject as a means of contributing to their own war activities in producing more uniform metallurgical coal was evidenced by invitations to present the results of this study before semiannual meetings of the Eastern States Coke Oven and Blast Furnace Association and the Coal Division of the American Institute of Mining and Metallurgical Engineers.

Roof Control

Any system that is effective in reducing roof falls in all parts of a mine is of definite benefit to the coal-mining industry. Continual interchange of moisture between mine air and roof rock of shaly composition is known to weaken the roof and increase roof falls. A study25/ was made at the Beech Bottom mine of the Windsor Power House Co. near Wheeling, W. Va.

24/ DeKay, H. E., Jr., Turnbull, L. A., Scudder, J. N., and Toenges, A. L. Control of Sulfur and Ash in Mine-Run Metallurgical Coal. Report 1: Bureau of Mines Rept. of Investigations 3742, 1943, 28 pp.

25/ Fish, E. L., Turnbull, L. A., and Toenges, A. L., A Study of Summer Air Conditioning With Water Sprays to Prevent Roof Falls at the Beech Bottom Coal Mine, West Virginia. Appendix by I. Hartmann: Bureau of Mines Rept. of Investigations 3775, 1944, 20 pp.

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of the operation of its water-spray, air-conditioning plant and its effect on minimizing roof falls in all parts of the mine. Laboratory tests showed that shales deteriorate when moist and are strongest when dry. After alternate wetting and drying, shales never returned to their original dry strength but became weaker after each change. Studies at the Beech Bottom mine showed that desorption and absorption of moisture by the shale were minimized by maintaining uniform temperature and moisture content of the mine air. Roof falls were diminished at this mine by installing an air-conditioning plant. Physical tests of the roof rock indicated that factors other than moisture changes, such as the modulus of elasticity and bending strength of the rocks and perhaps oxidation of the abundant pyrite in the roof, also contributed to roof failures. The study also indicated that moisture is absorbed from the roof rock during the winter and is deposited on the rock during the summer. This change from drying to wetting weakens the rocks and causes them to fall. Conditioning of incoming winter air will reduce absorption of moisture from the roof rocks. Air conditioning is desirable in winter as well as in summer.

Use of Diesel Engines Underground

Among the hazards that may attend the use of Diesel engines in mines, tunnels, and other underground operations, the presence of harmful constituents of the exhaust gas in such places must receive due consideration to prevent the formation of unsafe or unhealthful working environments. The latest report in a series of laboratory studies made to evaluate conditions that may exist when Diesel engines are used underground presents the results of tests conducted with a high-sulfur fuel (2.4 percent sulfur) to determine the effect on exhaust-gas composition when operating with a fuel of this type.[26] Essentially all of the sulfur in the fuel appeared in the exhaust gas as sulfur dioxide and sulfur trioxide; with increased temperatures the proportion of sulfur dioxide increased. It was concluded that the sulfur content of fuel for Diesel engines operating underground should be limited to 0.3 to 0.4 percent; otherwise, ventilation requirements would have to be increased to dilute the sulfur gases in the exhaust to concentrations permissible in working environments.

Grounding Electrical Equipment in Coal Mines

Although mine safety rules, codes, or standards state that electrical equipment in and about mining operations should be effectively grounded, the question arises concerning the effectiveness of grounding methods now in use. To be effective in minimizing shock and fire hazards, grounding must be capable of preventing dangerous potentials from building up on metal frames, casings, and other parts of equipment that might become electrically charged through accident or insulation failure.[27] A further objective is to

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26/ Berger, L. B., Elliott, M. A., Holtz, J. C., and Schrenk, H. H., Diesel Engines Underground. V - Effect of Sulfur Content of Fuel on Composition of Exhaust Gas: Bureau of Mines Rept. of Investigations 3713, 1943, 13 pp.

27/ Griffith, F. E., and Gleim, E. J., Grounding Electrical Equipment in and about Coal Mines: Bureau of Mines Rept. of Investigations 3734, 1943, 15 pp.

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minimize stray currents that may cause premature firing of electric squibs detonators, and devices fired electrically. Conclusions indicate that metal parts of machines used for loading and shortwall mining are not effectively grounded with the earth when they are at rest or are being moved over the mine floor. A single peg or rod driven into the mine floor also gives no assurance of making a connection of sufficiently low resistance to be satisfactory as a grounding electrode. Although, fish-plated, unbonded track ordinarily forms a satisfactory grounding electrode, the only dependable method to be employed in determining the effectiveness of a protective ground, either on the surface or underground, is from frequent measurements of the resistance of the grounding connection. Visual examination alone does not give any real measure of the effectiveness of protective grounds.

Ground-Resistance Measurements of Drill-Hole Casings

Questions have been raised concerning the necessity or advisability of providing protective grounding for drill-hole casings. It has been suggested that drill-hole casings be grounded effectively and permanently when electric conductors are installed in drill holes.[28] Test data appear to indicate, however, that drill-hole casings themselves are far superior to a rod as a grounding electrode. If effective grounding protection is to be achieved, resistance measurements must be made, because the true worth of the grounding circuit can be determined in no other manner.

Air Flow at Fan-Pipe Lines Discharge

As the ventilation of working places in mines is vital to the miners' health and safety, studies were made of the air flow at the discharge of fan-pipe lines in mines.[29] Data showed that, although the air-distributing conditions of free expansion into quiet air occur close to the pipe discharge, the mine walls themselves exert preponderant effects on flow conditions farther away for the range of relative sizes of drift and discharge openings involved in the tests. The change of velocity along the axis of the jet beyond a certain distance becomes an exponential function of distance in the instance of an enclosed jet rather than continuing as a power function, as for a free jet. In the same range of distances it was found that the distribution of velocities at right angles to the axis could be expressed approximately by a simple power function rather than by the complex series expressions developed theoretically for free jets. Converging pipe ends give about the same flow conditions as uniform-area ends, while diverging end pieces cause velocities to fall at much higher rates. The conditions of flow are practically independent of the velocity of discharge. Velocity ratios increase with size but are not affected appreciably by minor changes in shape.

28/ Griffith, F. E., and Gleim, E. J., Ground-Resistance Measurements of Drill-Hole Casings: Bureau of Mines Rept. of Investigations 3756, 1944, 7 pp.

29/ McElroy, G. E., Air Flow at Discharge of Fan-Pipe Lines in Mines. II Effect of Size and Shape of Pipe and of Adjacent Walls on Velocity and Entrainment Ratios: Bureau of Mines Rept. of Investigations 3730, 1943, 30 pp.

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Mine-Fan Signal Alarms and Power Releases

Any condition that interrupts the ventilating current or changes its normal course through mine workings is a distinct hazard and should receive serious consideration.30/ If the ventilating fan should stop, it would be impossible to ignite a resultant accumulation of explosive gas by electrical arcs or sparks if the electrical power were cut off at the surface. Hand operation of the cut-off has proved disastrous in several instances. Devices can and should be installed that automatically open the underground circuits if the fan ceases to function properly. Several types of power release and signal alarms now in use described in detail.

Construction of Mine Ventilating Doors

Adequate volumes of pure air must be supplied at the working faces, along the haulageways, and wherever men work in mines, to dilute and carry away methane liberated from the coal and adjoining strata, noxious gases evolved by explosives, carbon dioxide exhaled by men and formed by oxidation of carbonaceous material, and any other gases and dusts that may be present in mine workings. Careful construction and maintenance of mine doors will minimize leakage of air and conserve an adequate supply to working places. Mine-door and doorframe construction merit careful consideration, based upon efficiency rather than initial cost.31/ Mine-door construction and installation are discussed.

Precautions for Old Mine Workings

The attention of the Bureau has been called to the lack of consideration or utter disregard of an old and presumably widely known mine safety rule, namely, the necessity for precaution when approaching old or abandoned workings of a mine.32/ Representative examples are given of scores of accidents that have occurred in relatively recent years and that continue to occur far too frequently. Recommendations are made for safe-operating practices.

Permissible Mine Equipment

The Bureau continued to investigate electrical equipment used in mines in connection with the prevention of mine explosions and fires. A list of permissible mine equipment, which was tested and approved during the calendar year 1943, was published.33/

Gas Explosions and Use of Explosives

To insure continued safety when permissible explosives are used, the Bureau made physical, chemical, and control tests on a number of explosives

30/ Fene, W. J., and Weaver, H. F., Mine-Fan Signal Alarms and Power Releases: Bureau of Mines Inf. Circ. 7262, 1943, 8 pp.

31/ Hartley, J. C., and Moschetti, A. C., Standardized Construction of Mine Ventilating Doors: Bureau of Mines Inf. Circ. 7280, 1944, 4 pp.

32/ Harrington, D., and Warncke, R. G., Precautions to Be Taken When Approaching Old Mine Workings: Bureau of Mines Inf. Circ. 7288, 1944, 20 pp.

33/ Gleim, E. J., Permissible Mine Equipment Approved During 1943: Bureau of Mines Inf. Circ. 7283, 1944, 5 pp.

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and blasting devices.[34] Eight brands of permissible explosives were added to the active permissible list as a result of tests, changes in brand names, or transfers from the inactive list. Twenty-two permissible explosives were transferred from the active to the inactive list. The present list contains 180 brand names. Nine models of Cardox on the list of permissible blasting devices last year remain approved. The work on permissible explosives and blasting devices has been described in connection with the discussion of the work of the Explosives Division.[35]

Burning Rate of Fuse

Many accidents are caused by not knowing the burning rate of fuse due to the erroneous impression that fuse always burns a foot a minute and the widespread use of short fuses. It is recommended[36] that all users of fuse know the burning rate of the fuse concerned. This fact can be determined by timing a length of burning fuse in the place and under the conditions to which it is subjected during blasting. Closer supervision of blasting practices is advocated. A minimum length of fuse should be designated as a safety factor. To be on the safe side, 2 feet a minute should be assumed as the burning rate, and the use of electrical detonators or a "warning fuse" should become standard practice.

Inflammability and Ignition Temperatures of Acetic Anhydride

The limits of inflammability and ignition temperatures of combustible gases, vapors, and solids are of practical importance in the promotion of safety in mining and industry. Acetic anhydride is especially important at this time because of its direct application in the manufacture of munitions.[37] The temperature limits between which air saturated with acetic anhydride vapor forms inflammable mixtures were found to be 47.3° and 74.4° C. (117° and 166° F.). These values correspond to concentrations of 2.67 and 10.13 percent by volume. All mixtures between these percentages at the temperatures stated are inflammable. The flash point by the standard closed-cup tester was found to be 124° F. (51° C.). The ignition temperatures were found to be 392° C. (738° F.) in air and 361° C. (682° F.) in oxygen.

Acetylene-Generator Explosions

The use of acetylene has expanded greatly during the past 2 years. At the request of the War Production Board, the Bureau of Mines investigated the causes of explosions that occurred in acetylene-generator plants in shipyards

34/ Tiffany, J. E., and Gaugler, Z. C., Active List of Permissible Explosives and Blasting Devices Approved Previous to June 30, 1943: Bureau of Mines Rept. of Investigations 3736, 1943, 23 pp.

35/ Huff, W. J., Studies on Explosives and Explosions, Fiscal Year 1943: Bureau of Mines Rept. of Investigations 3745, 1944, 49 pp.

36/ Harrington, D., and Warncke, R. G., The Burning Rate of Fuse: Bureau of Mines Inf. Circ. 7281, 1944, 10 pp.

37/ Jones, G. W., Scott, F. E., and Scott, G. S., Limits of Inflammability and Ignition Temperatures of Acetic Anhydride: Bureau of Mines Rept. of Investigations 3741, 1943, 5 pp.

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on the Pacific coast.[38] These shipbuilding companies erected acetylene-generator equipment, which was soon found to be inadequate to meet expanding acetylene requirements for welding, cutting, shrinking, and other purposes. In some instances the companies found it necessary to operate their equipment at rates greater than deemed consistent with safe operating practice. It was found that carbides meeting Federal Specifications O-C-101, Amendment 1, December 27, 1938, did not prove entirely safe for use under the observed conditions. Some manufacturers have been lax in permitting foreign material to get into the carbide and thereby varying its quality. A majority of the explosions occurred near the end of a run when the generators were at temperatures of 60° to 75° C. and when the liberated acetylene gas carried enough water vapor to heat fine-size carbide to critically high temperatures, thus becoming the source of ignition of the compressed acetylene in generators. It is recommended: (1) That the Federal specifications be amended, (2) that the Underwriters' Laboratories, Inc., make approval tests on the 500-pound, double-rated generators involved in the explosions so that the time for generation of the charge is not less than 2 hours and 15 minutes and the generator-water temperature should not exceed 150° F.; (3) that all pea- or quarter-size carbide be passed through a 0.75-inch screen to aid in eliminating trash and oversize carbide; (4) that the use of second-hand, 100-pound drums for shipment of carbide be discontinued; (5) that the generators be dismantled and cleaned thoroughly at least once each month; (6) that routine chemical analyses and physical tests be made of the carbide used in generators; and (7) that the acetylene generator plants be redesigned to operate at lower specified pressures, if the above recommendations do not solve the explosion problems.

Hazards from Common Gases and Vapors

In the interest of safety and health in mining and other industries, the Bureau has investigated the hazards that confront workers from the presence of common gases and vapors that may accumulate in dangerous concentrations under some conditions. Information has been presented[39] to provide data on the inflammability of certain of these gases and vapors so that workers may be informed how to take the necessary precautions to protect themselves and to save the injured victims of demolished operations. Leakages, insufficient ventilation, open lights, smoking, and nonpermissible electrical equipment are among the more common hazards.

Coal-Mine Explosions and Fires During the Fiscal Year 1943

While an encouraging reduction was noted in the frequency and severity of mine explosions up to 1940,[40] 152 fatalities resulted from explosions

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38/ Jones, G. W., Scott, G. S., Kennedy, R. E., and Hoff, W. J., Explosions in Medium-Pressure Acetylene Generators: Bureau of Mines Rept. of Investigations 3755, 1944, 20 pp.

39/ Jones, G. W., Hazards from Common Gases and Vapors Encountered at Surface Disasters: Bureau of Mines Inf. Circ. 7287, 1944, 15 pp.

40/ Harrington, D., and Fene, W. J., Coal-Mine Explosions and Coal- and Metal-Mine Fires in the United States during the Fiscal Year Ended June 30, 1943: Bureau of Mines Inf. Circ. 7274, 1944, 27 pp.

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during each of the fiscal years 1942 and 1943, 163 in 1941, and 206 in 1940. Lack of proper precautions by members of the coal-mining industry seems to be indicated by the data on the causes of the disasters.

Use and Misuse of Flame Safety Lamps

No excuse can be accepted for an explosion caused by a flame safety lamp.41/ Of all the preventive measures necessary to eliminate coal-mine explosions, the problem of correct use of safety lamps should be the easiest to control, yet the records show that many operators and workers are still unaware of the dangers involved in using such equipment. Suggestions are given for the care and use of flame safety lamps.

Accidents Due to Misuse of Explosives

Examples of the misuse of explosives and faulty blasting practice were compiled42/ and recommendations were made on procedures that should be avoided when explosives are handled or used. Blasting accidents are nearly always serious, and many may be eliminated by a determined educational campaign. A rigid law should be enacted to require that all persons who engage in blasting should be prohibited from doing so until they pass an examination indicating their competency for handling explosives.

Elimination of the hazards associated with explosives begins on the surface.43/ It has also been proved that, in spite of the dangers involved, explosives can be transported safely. More coal-mining companies are using only permissible explosives and blasting devices. Efficient mining companies operate by a code of rules and standards to guide both officials and employees in the use of these explosives and blasting devices. Correct and proper supervision is essential to complete safety. Competent shot firers must be employed to minimize hazards.

There has been too much carelessness in handling blasting caps.44/ Children must be taught in the schools and by parents of the hazards of explosives to themselves and to others. Too many children come into possession of blasting caps through the negligence of older persons. The mining industry can greatly help in reducing accidents due to such negligence.

Exploration for New Coals

Coking Coals

To find new coals that can be used in coke making and to reduce transportation costs to coke plants in the Western and Southern States, explorations of coal deposits were made in areas at or near Madrid, N. Mex.;

41/ Tomlinsen, Walter H., Use and Misuse of Flame Safety Lamps: Bureau of Mines Inf. Circ. 7271, 1944, 14 pp.

42/ Harrington, D., and East, J. H., Jr., Accidents Due to Misuse of Explosives: Bureau of Mines Inf. Circ. 7259, 1943, 14 pp.

43/ Fitzgerald, L. G., Some Suggestions on Care in the Use and Handling of Explosives in Coal Mines: Bureau of Mines Inf. Circ. 7278, 1944, 7 pp.

44/ Harrington, D., and Warncke, R. G., Accidents to Children from Blasting Caps: Bureau of Mines Inf. Circ. 7275, 1944, 13 pp.

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Kemmerer, Wyo.; Paonia, Colo.; and Fort Payne, Ala. The investigation in these areas included exploration to determine the thickness, extent, physical characteristics in and surrounding the beds, and the minable reserves. The chemical and coking properties of the coals were determined from the coal cores. Some of these areas can profitably serve as additional sources of coals needed by western and southern coke plants.

Coal Reserves in Areas of Critical Fuel Supplies

The critical coal shortage in the Northwest and the demand for fuel for war plants and Army camps justified explorations to determine minable reserves of coal in California, Nevada, Oregon, and Washington.

Reconnaissance of a lignite area in Amador County, Calif., indicated a favorable topography for stripping, but the available information suggests that the areas are not continuous and that the thickness of the bed is variable. Diamond drilling at closely spaced locations to determine the extent of beds and their character is recommended. Briquetting tests of this lignite by the Bureau of Mines show that it briquets easily without use of binder. Valuable refractory clays lie above and below the lignite in some places. The topography of an area 5 miles east of Dos Rios in Mendocino County is mountainous, and at present the region is not accessible by railroad. Samples of coal from outcrops and abandoned mines indicate areas of subbituminous coal of fair quality in this vicinity.

Except for intermittent, small-scale mining of poor-quality coal little coal has been produced in Nevada. Construction of Army air fields and magnesium plants made the development of local sources of fuel desirable. Exploration by diamond drilling of a coal area in Esmeralda County was not completed. Coal from one slope mine shows possibilities of improvement by washing.

A reconniassance of the Coos Bay field in Oregon showed probable reserves of subbituminous coal suitable for war industries and domestic use in the Northwest. Exploration of the area by means of core drilling showed considerable variation in the thickness and extent of the minable areas, as represented by cores from the nine diamond-drill holes completed. Well-planned drilling locations will therefore be necessary to determine the best minable reserves.

Reconnaisance of an area near Toledo in Lewis County, Wash., indicated a large reserve of lignite, which could be recovered by strip mining. However, because this type of mining requires a large investment in equipment, exploration by diamond drilling to determine minable reserves is recommended. Three areas of subbituminous coal in the Hanaford Valley near Centralia, Wash., appear favorable for strip mining, but exploration is recommended to determine the depth of overburden and the thickness and extent of these coal beds.

Examinations and Reports for the Smaller War Plants Corporation

At the request of the Smaller War Plants Corporation, examinations and reports were made of one coal property in Mercer County, Pa., and of a

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second in Tuscarawas County, Ohio. This work was done in connection with granting Government aid for expanding operations.

PREPARATION OF COAL

Improvement of Coals for Special Purposes

Preparation of Coal for Production of Synthetic Liquid Fuels

Investigations of the development of processes for synthesizing liquid fuels from American coals have emphasized the need of examining (1) suitable coal reserves and (2) methods of preparing coals for such use. The Bureau of Mines is conducting an intensive program of float-and-sink tests and general preparation studies on large samples of reserves of middle- and low-grade coal and lignite deposits of the Midwestern and Western States. These studies will facilitate the use of these reserves of fuel for future production of liquid fuels, as well as in the general utilization of these coals for other purposes. This investigation may eventually be of even greater value in the development of local industries in areas where these vast fuel reserves are available. The preparation of those coals to make them suitable for the manufacture of synthetic liquid fuels will require extraction of more of the ash than is at present required for other special purpose fuels. Improvement of existing processes or the development of new processes to produce low-ash coal will benefit all industries using coal for special purposes.

Low-Ash Coke for Carbon Electrodes

The possibility of using coke from low-ash Appalachian coals for carbon electrodes in the aluminum industry was investigated.45/ Float-and-sink studies were made on one Alabama and six eastern Kentucky low-ash coals to determine how pure a float coal could be obtained. Although the float portions first crushed to pass a No. 20 sieve showed considerable reduction in mineral matter, none of them met all the rigid specifications with respect to maximum allowable contents of total ash, iron, silicon, calcium and sodium, and sulfur, as specified for carbon electrode manufacture by the aluminum industry. Tests of float portions of the seven coals, obtained on 1.30 specific-gravity solutions, showed that the ash content could be reduced further by acid treatment. These float coals, crushed to pass a No. 60 sieve, were digested at room temperature for 24 hours with an equal weight of solution containing 5 percent HCl and 5 percent HF, with 1 part per million of tannic acid as wetting agent. Analyses of the ashes of these acid-treated float coals showed that the calculated amounts of iron, silica and calcium present in the cokes prepared from three of the Kentucky coals were within the requirements for carbon-electrode manufacture. Ash removal by the Trent process on the seven coals was not nearly as complete as by float-and-sink methods.

45/ Selvig, W. A., Ode, W. H., and Gibson, F. H., Coke from Low-Ash Appalachian Coals for Carbon Electrodes in Aluminum Industry with a chapter on Comparison of Results Obtained by Trent Process for Cleaning Coal with those by Float-and-Sink Methods by Joseph D. Davis: Bureau of Mines Rept. of Investigations 3731, 1943, 22 pp.

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Marginal Special-Purpose Coals

Rapid expansion of the steel and other premium-coal-consuming industries has built up an urgent need for the development of new reserves of special-purpose coals. The possibilities of broadening the reserves of suitable coals lie very largely in improving the preparation of the remaining known reserves of "next-best" coals. Such coals are available in enormous volume and present an intricate variety of preparation problems. For example, in the industrial area of western Pennsylvania, an intensive study is being made of Pittsburgh-bed coal in marginal areas where its sulfur content is too high for production of metallurgical coke that will meet present standards. Depletion of low-sulfur coal in the western Pennsylvania industrial area has advanced to the point where either higher-sulfur coals must be used or coal of a satisfactory sulfur content must be properly prepared or blended with low-sulfur coals. Continuous sampling and classification of high-sulfur coals as mined indicate that they may be separated into a high-sulfur grade and a low-sulfur grade with more than half available as metallurgical coal conforming to current specifications. The remaining minable areas of low-volatile coal in the Georges Creek Basin of Maryland are being investigated to determine whether special purpose coals can be prepared by coal-washing methods. The washing characteristics of low- and high-volatile coals of southern West Virginia are being studied to determine their suitability for special purposes.

Miscellaneous Preparation Studies

Development of Improved Methods of Coal Preparation

As a supplement to studies of the washing characteristics of marginal coals, it was necessary to develop more precise methods for separating high- and low-grade fuel and the associated refuse. This work consists essentially in devising means for separating coal into two grades as compared with the older and simpler problem of separating coal from rock materials and involves the more difficult tasks of separating low-ash, low-sulfur components of the matrix, both from associated refuse and from inferior coal with higher ash and sulfur contents. The project demands more precisely controlled operations and separations at lower specific gravities than can be made by conventional coal-cleaning processes, as usually operated.

Many waste and semiwaste products that contain substantial proportions of good bituminous coal have been rejected because no use could be made readily of the raw material. This coal can be salvaged economically by suitable preparatory treatment. Substantial tonnages of clean bituminous coal can be recovered from dirty coal left after stripping operations in Illinois, Indiana, and western Kentucky, and large amounts of fine coal can be salvaged from these same areas through improved cleaning and dewatering methods. Present mining practices discard as waste, not only much of the bony coal of the Thick Freeport bed in western Pennsylvania but also a substantial amount of good coal which is mixed with mine rock in eastern Ohio, southern Pennsylvania, and northern West Virginia. It is estimated that more than a million tons of good coal, comparable in quality to that

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currently marketed in the Pittsburgh industrial area, could be salvaged each year at the larger mines of western Pennsylvania by treatment of waste material.46/ Field surveys are being made of the losses of coal in mining and preparation operations to appraise the tonnage and economic value of usable fuels now lost by wasteful practices. From these surveys practical methods of recovery can be devised and recommended.

Characteristics of Coal and Its Associated Impurities

The physical, chemical, and petrographic characteristics of coal and the composition of associated impurities were evaluated in connection with an investigation of mechanical cleaning of coal.47/ Coal preparation was shown actually to begin at the face of the coal bed in the mine. The most important single characteristic of both coal and its impurities, from the standpoint of cleaning, is specific gravity. Among other characteristics related in one way or another to coal preparation are rank, petrographic composition, structure and breakage, size composition, hardness, strength, friability, grindability, slacking or weathering properties, and the amount and composition of ash-forming impurities and of sulfur. These characteristics, as they affect the selection of coking coals, were considered.

Washability Studies

Washability studies were made of run-of-mine coal from the Brockwood bed, Alabama, in connection with tests of coking coals at a byproduct plant at Holt, Ala. Washability data of run-of-mine coal from the American coal bed, Virginia mine, were obtained for use in planning a new washer required because of proposed changes in mining methods. Contracts, based on the data obtained, have been let by the mining company for the new preparation plant. Coke breeze from a dump pile was subjected to washability studies to determine its suitability for replacing old mine refuse being used for producing steam coal. Plans, based on this study, are well-advanced for the installation of treating equipment at the coke-breeze dump. At the request of the Deputy Solid Fuels Administrator for War, an investigation was made of the practical recovery of semianthracite from culm piles at Merrimac and Shelby Junction, Va. It has been estimated that these piles contain about 340,000 tons of 9/16- to 0-inch culm. The study showed that about 72 percent can be recovered by table washing. The ash content of the culm was 21 percent. A suitable treating plant was recommended and its costs were estimated for the Deputy Solid Fuels Administrator for War.

46/ Fraser, T., Kelley, J. A., and Graham, H. G., Salvage of Coal from Mine Refuse in the Pittsburgh District: Bureau of Mines Rept. of Investigations 3768, 1944, 23 pp.

47/ Yancey, H. F., Geer, M. R., and Davis, J. D., Characteristics of Coal and Its Associated Impurities. Chap. 2 in Coal Preparation (D. R. Mitchell, ed.): Am. Inst. Min. and Met. Eng., 1943, pp. 31-79.

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One of the Bureau engineers collaborated with the Brazilian National Department of Mineral Production in a study of washing characteristics of Braziliazan coals.[48]

Mechanical Cleaning

Recent introduction of small coal jigs in Alabama, Pennsylvania, and Tennessee to meet the needs of hundreds of truck-mine and other low-tonnage operators has increased the demand for information on cheap and economical coal-cleaning equipment.[49] The publication describes two small jigs of the Montgomery type and one of the Elmore type and includes performance data obtained recently in cooperation with the University of Alabama on one of the Montgomery-type jigs. This jig has a capacity of 5 to 10 tons per hour and was studied at the installation operated by the Pen Coal Co. at the Pen Wadsworth mine near Birmingham, Ala. Samples of the jig products (feed, washed coal, and refuse) were screened into the following sizes: 1 1/4- to 3/4-inch, 3/4- to 3/16-inch, 3/16-inch to 14-mesh, and minus 14-mesh. Each size was subjected to float-and-sink fractionations, and the resulting products were analyzed for ash. The jig treatment of the four sizes named reduced the ash contents from 6.5 to 4.1 percent, from 11.8 to 5.3 percent, from 18.1 to 9.5 percent, and from 28.0 to 23.3 percent, respectively. Corresponding percentages of the total available coal recovered as washed coal were 98.5, 98.0, 98.3, and 96.8. For the composite minus-1 1/4-inch jig feed, 97.3 percent of the total available coal was recovered as washed coal, and the ash content was reduced from 16.2 to 8.7 percent. Both the recoveries and ash reductions on the two coarsest sizes about equaled those obtained from single-compartment jigs, regardless of size or type. Recoveries on the two finest sizes were quite satisfactory, but the ash reductions were slightly substandard. An additional 1 or 2 percent reduction in ash can be expected with improved operation of the jig.

Concentrating Tables

A discussion of developments in the wet-process coal-washing systems from the early bumping tables to present-day, differential-motion, concentrating tables was contributed to a recent volume on coal preparation.[50] Principles of the tabling process, the importance of correct operating conditions, the efficiency of the concentrating table as a coal-cleaning device, the evaluation of table performance from washability data, and the comparison with other cleaning devices were concisely discussed.

Screening of Coals

In coal preparation, sizing is generally accomplished by passing the coal over screens. Different types of screening machinery, screening practices for anthracite and bituminous coal, and performance ratings of screening

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48/ Fraser, T., and Paiva Abreu, Alvaro de, Lavabilidade de Carvões do Brasil (Washing of Brazilian Coals): Brazil. Dept. nacional da produção mineral, Laboratório da produção mineral Boletim, No. 13, 1943, 185 pp.

49/ Gandrud, B. W., and Bator, G. T., Some Small Coal Jigs for Mechanical Cleaning of Coal at Truck Mines and Other Low-Tonnage Operations: Bureau of Mines Rept. of Investigations 3718, 1943, 17 pp.

50/ Gandrud, B. W., Concentrating Tables, Chap. 13 in Coal Preparation (D. R. Mitchell, ed.): Am. Inst. Min. and Met. Eng., 1943, pp. 425-456.

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equipment were discussed in a recent publication.51/ This chapter presents numerous data showing results obtained with various types of screening equipment and for coals under different physical conditions.

Methods for Loading Coals

The operations of commercial loading plants in transferring coal from preparation machines to railroad car, truck, or barge, in which it is to move to market, have been described with reference to minimum breakage and segregation of coal and to maintenance of uniformity in the different shipments.52/ The extent of expected degradation of coal during typical conditions of storage, loading, and shipment is discussed. Methods of loading and loading devices for handling anthracite and bituminous coal are describe

STORAGE OF COAL

Action of Coal in Storage

Valuable new information on the action of coal in storage was gained through field surveys, laboratory investigations, questionnaires, and mutual exchange of ideas between representatives of the coal industry and Bureau engineers. The storing characteristics of a series of coals were investigated, among them coals mined in the Midwestern States, the New Mexico-Arizona area, the Oklahoma-Arkansas area, and Washington. Additional studi were made of materials used for capping coal piles, particularly of the effect of weathering and length of life of sisal kraft paper. The effect o the durability of capping materials of the increased vapor pressure of high moisture coals resulting from increased temperature was determined. Consulting service on various problems of coal storage was given to the Solid Fuels Administration for War, the Federal Public Housing Authority, the Department of Justice, the Navy Department, the War Department, and other Federal institutions, as well as many industrial plants.

Pointers on the Storage of Coal

Frequent questions arising in the minds of coal users concerning the effect of storage on the physical and chemical properties of coal are answered in a recent article.53/ A concise review is given of early and more recent work on storage of coal and related problems conducted by the Bureau of Mines. The effect of rank of coal on slacking, important factors affecting spontaneous combustion, and methods of its prevention are discussed.

51/ Fraser, T., and Johnson, J. S., Screening. Chap. 5 in Coal Preparati (D. R. Mitchell, ed.): Am. Inst. Min. and Met. Eng., 1943, pp. 127-1

52/ Fraser, T., Loading. Chap. 23 in Coal Preparation (D. R. Mitchell, ed. Am. Inst. Min. and Met. Eng., 1943, pp. 699-720.

53/ Barkley, J. F., Pointers on the Storage of Coal: The Black Diamond, vol. 111, Sept. 18, 1943, pp. 18-19.

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Preventing Spontaneous Combustion in Stored Coal

Whether a particular coal under given storage conditions will heat from ontaneous combustion to any undesirable extent depends upon many factors. thorough discussion of the significance of the several factors directly lated to heating of the coal pile during storage, satisfactory methods of orage, and methods of measuring and controlling temperatures was presented a recent paper.54/ The factors include: (1) The tendency of the particular coal to absorb oxygen; (2) the temperature at which the coal is piled;) the fineness of any pyrite present; (4) the original size of coal and e dependent surface area; (5) the tendency of the coal to slack; (6) the isture conditions; (7) the volume of air available to the coal permitted conditions of ventilation throughout the storage piles; (8) the presence foreign substances, such as wood, straw, and refuse; (9) the possibilities dissipating any heat developed; and (10) any added heat from external urces. If these complex factors are evaluated correctly and means are ailable to carry out proper methods needed in each instance, it is not fficult to store coal satisfactorily. Satisfactory storage methods must devised primarily with considerations of the type and size of coal, its eedom from foreign materials, and practices that either prevent access of r to the coal entirely or provide for enough air throughout the pile to rry away the heat as rapidly as it develops. Methods of storage condered included: (1) Storing under water; (2) storing in an open pit in e earth; (3) storing slack in layers, either compacted or loose; (4) pping the coal pile with airtight coverings; (5) storing in bins, bunkers, d silos; (6) storing sized coals; and (7) storage in the home.

Storage of Subbituminous Coal

Storage of 10 tons of lump subbituminous coal for 8 months in a tight n in a typical six-room brick bungalow showed no significant changes in e physical and chemical properties of the coal, and the stored coal gave cellent performance in a hand-fired furnace.55/ The coal was leveled in e bin and covered with wrapping paper to prevent flow of air through the le. During the storage period the moisture content changed from 23.6 to .1 percent, the heating value from 13,270 to 13,060 B.t.u. per pound (dry, h-free basis), the friability from 21 to 26 percent, and the Bureau of nes slacking index from 65 to 61 percent. Visual inspection of the coal vealed little degradation. The maximum temperature of 80° F. in the coal s reached after 72 days and then decreased gradually to 65° F. During e 8 months' storage period the outside temperature ranged from 18° to 0° F. Performance of the stored coal in a hand-fired furnace in the same sidence during cold weather under normal conditions of use demonstrated at an average of 2.95 pounds of 9,850 B.t.u. coal, or 23,500 net available

54/ Barkley, J. F., Preventing Spontaneous Combustion in Stored Coal: Smoke Prevention Assoc. of America, Inc., Manual of Instructions on Proper Firing Methods, 1943, pp. 1-7a.

55/ Landers, W. S., and Parry, V. F., Domestic Storage of Subbituminous Lump Coal and Its Performance in a Hand-Fired Furnace: Bureau of Mines Rept. of Investigations 3759, 1944, 17 pp.

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B.t.u. was required per day per degree day (60° F. base). Fly-ash losses during the test were 2.4 percent of the ash charged in the coal. During the open-draft periods of the test the indicated over-all heating efficiency was about 69 percent. Maximum efficiency obtainable with this coal under practical conditions was 80.9 percent.

Studies of the storage of large quantities of subbituminous slack coal for industrial purposes was continued. The Subbituminous Coal and Lignite Section of the Bureau of Mines at Golden, Colo., in cooperation with the Great Western Sugar Co., Brush, Colo., studied stored coal in an open concrete pit, filled with 13,300 tons of coal from various mines of the Northern Colorado field, during the period from February to May 15, 1944. The coal was placed in 3-foot layers and compacted by a tractor to a bulk density of 58 pounds per cubic foot. The total depth of coal in the bin, after compacting, was about 15 feet. Table 1 give the results of temperature determinations of the coal pile. The data show that practically all oxygen has been eliminated from the gases beneath the surface of the pile and that about one-third of the oxygen of the air was absorbed by the coal and not liberated as products of oxidation. This study and earlier demonstrations prove that subbituminous coal can be stored satisfactorily in open, dry pits.

Influence of Storage on Caking and Coking Properties of Coal

The effect of storage or oxidation upon the coke-making properties of coals is of great importance to commercial coke-oven operators who must either store large amounts of coal to insure continuous plant operation or ship coal for long distances which may involve extended storage periods, either at the mine or at the site of the coke ovens. Two representative samples of coal from the Eagle and the Elkhorn No. 3 coal beds have been recently tested and their relative storing qualities determined. Four-hundred-pound samples of these coals, stage-crushed to 0- to 1/4-inch size, were oxidized progressively at 100° C. in air in a rotary, steam-jacketed, oxidation apparatus and then carbonized at 800° C. Values for the "durability of coking power" are given in table 2, and the effects of these accelerated weathering tests on the coke strength indexes are shown graphically in figure 3. For comparative purposes data that have been obtained on two samples of Pittsburgh-bed coal from different mines have been included.

The length of time that a sample of coal can withstand the action of air at 100° C. to cause a 15-percent reduction in its coke-strength index is defined as the "durability of coking power." This value for the Eagle-bed coal is almost as large as that for the sample of Pittsburgh-bed coal from the Warden mine and is double that for the sample of Pittsburgh-bed coal from the Bruceton mine. The coking powers of the Elkhorn No. 3-bed coal are only 46 percent as resistant to storage as those of the sample of Pittsburgh-bed coal from the Bruceton mine.

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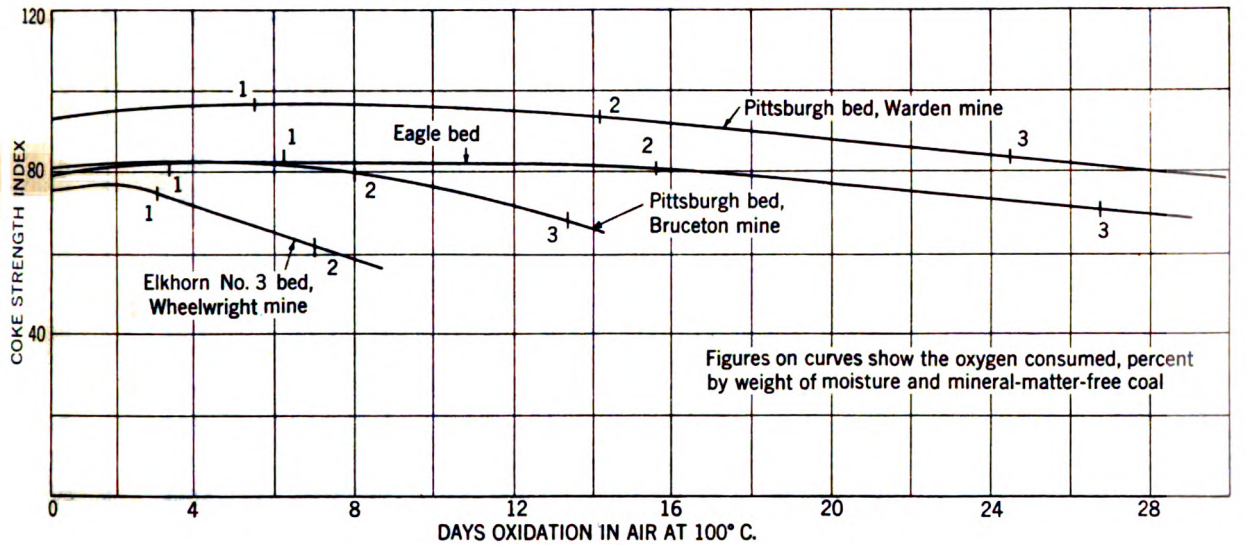

FIGURE 3.- Effects of storage (acceleration) of coal on strength index of coke.

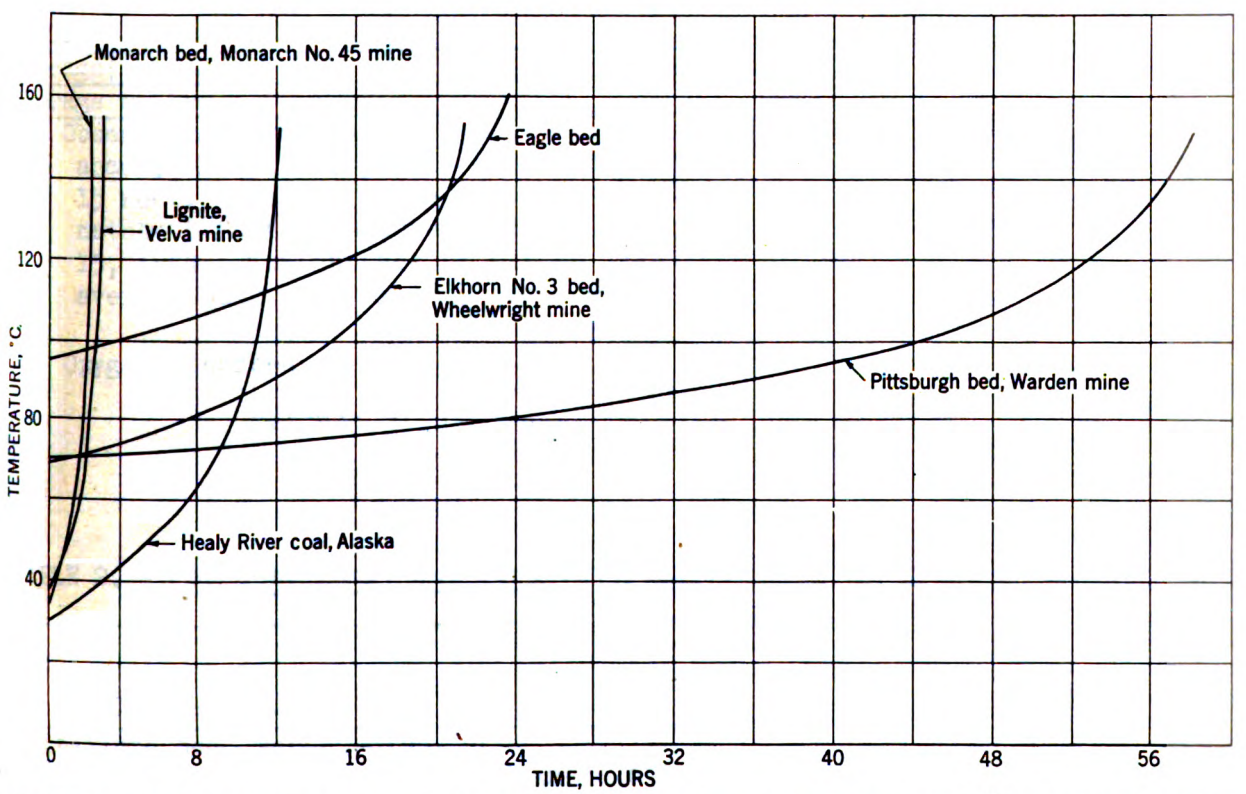

FIGURE 4.- Self-heating of dry, 0 to $\frac{1}{4}$-inch coal in an atmosphere of 85- percent oxygen.

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TABLE 1. - Observed temperature and composition of gas in subbituminous coal stored in open pit at Brush, Colo., June 27, 1944[1/]

Station number	Temperatures in the coal °F.			Composition of gases at 4 feet, percent				
	3 feet	6 feet	9 feet	CO_2	O_2	CO	N_2	Oxygen absorbed[2/]
1	130	98	85	13.5	0.3	0.0	86.2	32
2	132	108	92					
3	140	110	90	12.0	.2	.0	87.8	40
4	135	108	92					
5	132	110	95	12.1	.3	.0	87.6	40
6	125	100	82					
7	137	108	90	12.1	2.5	.5	84.9	25
8	125	105	82					
9	122	97	78	7.7	4.3	.0	88.0	42
10	125	105	85					
11	133	105	87	6.9	10.2	.1	82.8	12
12	130	105	85					
13	128	103	87	12.4	.2	.0	87.4	39
14	133	110	90					
15	128	105	85	12.4	.8	.3	86.5	34
16	140	110	87					
17	132	108	85	11.3	.4	.0	88.3	44
18	135	112	82					
19	137	110	85	14.1	.2	.0	85.7	30
20	132	100	83					
Average	132	106	86	11.5	1.9	.1	86.4	33

Average entire pit, 108° F.

1/ Observations made at 20 stations, 30 feet from walls of pit and 40 feet apart. Length of pit is 423 feet, width 100 feet, and coal depth about 15 feet. The pit contains about 13,300 tons of coal placed in approximately 3-foot compacted layers during the period from February to May 15, 1944. Top surface of pit is level and compacted to give total average bulk density of 58 pounds per cubic foot.

2/ Oxygen absorbed, percent $= 100 \times \dfrac{\dfrac{N_2}{0.809} - \left(N_2 + CO_2 + O_2 + \dfrac{CO}{2}\right)}{\dfrac{N_2}{0.809} - N_2}$, Based on ultimate CO_2 = 19.1 percent.

TABLE 2. - Sources, rank, and durability of coking power of the coals tested

Coal and Source	Rank	Durability of coking power, T_{15} days	Ratio to Pittsburgh bed, Bruceton mine
Pittsburgh bed, Warden mine, Allegheny County, Pa.	High-volatile A	28.5	2.11
Pittsburgh bed, Bruceton mine, Allegheny County, Pa.	do	13.5	1.00
Eagle bed, (prospect hole), Kanawha County, W. Va.	do	27.8	2.06
Elkhorn No. 3 bed, Wheelwright mine, Floyd County, Ky.	do	6.2	.46

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The small figures on the curves of figure 3 show how much oxygen the coal has consumed during the corresponding time of accelerated weathering as shown on the (abscissa). Examination of these curves indicates that the Eagle-bed coal oxidizes at a slower rate than any of the other three coals while the Elkhorn No. 3-bed coal consumes oxygen faster than any of the other coals shown.

Spontaneous Heating of Stored Coal

The relative tendencies of a number of coals to heat spontaneously in storage have been measured in the Bureau of Mines laboratory by two different methods. In the first procedure, the characteristic oxidation rate of a 0-1/4-inch sample of the coal at 100° C. in air is measured through the use of a 50-pound, rotary, steam-jacketed equipment similar in operation to the 400-pound equipment described earlier.[56] The second procedure involves the drying of a sample of 0- to 1/4-inch coal at 100° C. in an inert atmosphere and then placing the dried coal in an adiabatic type calorimeter of 110 pounds capacity, heating to the temperature at which it is desirable to start the test, and then passing oxygen up through the apparatus at such a rate that an atmosphere containing 85 percent or more oxygen is maintained in contact with the coal. The rise in temperature of the coal is a measure of the tendency of the coal to heat spontaneously in storage.

Table 3 gives the results that have been obtained for several of the coals tested by the two methods. The agreement between the two types of tests is good for the high-volatile A coals and seems fairly satisfactory for the subbituminous coals and lignite. These latter coals are much more apt to cause trouble through spontaneous heating during storage than the high-volatile A coals, and because of their high reaction rates, it is difficult to measure accurately their tendencies to heat.

Figure 4 gives the experimental self-heating curves that were obtained from the adiabatic calorimeter tests. To compare the tendencies of these coals to heat, it is necessary to calculate the heating rates at some definite temperature, such as 100° C. Thus, although the curve for the Eagle coal starts at slightly less than 100° C. and the Pittsburgh bed between 70° and 80° C., their self-heating tendencies can be compared by a comparison of their rates of temperature rise at 100° C. The self-heating curves show that the Monarch coal and the lignite samples are the most likely to heat in storage; the Healy River coal is somewhat less likely to cause trouble; the Elkhorn No. 3 bed coal is much less likely to heat than the lower-rank coals, but it is about twice as liable to cause trouble as the Pittsburgh-bed and Eagle-bed samples. The average numerical values of the relative tendencies for these coals to heat spontaneously are given in the last column of Table 3.

56/ Schmidt, L. D., and Elder, J. L., Atmospheric Oxidation of Coal at Moderate Temperatures - Rates of the Oxidation Reaction for Representative Coking Coals: Ind. Eng. Chem. (Ind. Ed.), vol. 32, February 1940, pp. 249-256.

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TABLE 3. - Comparison of the tendencies of various coals to heat spontaneously during storage

Coal and source	Rank	Characteristic oxidation rate at 100° C. R_a (X=1) 1/	Ratio to Pittsburgh-bed coal	Self-heating rate at 100° C., °C. per hr.	Ratio to Pittsburgh-bed coal	Average ratio to Pittsburgh-bed coal
Pittsburgh bed, Warden mine, Allegheny County, Pa.	High-volatile A	0.13	1	1.83	1	1
Eagle bed (prospect hole), Kanawha County, W. Va.	do	.12	.9	1.12	.6	.8
Elkhorn No. 3 bed, Wheelwright mine, Floyd County, Ky.	do	.27	2.1	4.0	2.2	2.2
Monarch bed, Sheridan County, Wyo.	Subbituminous B	3.3 2/	45 3/	143	78	62
Healy River coal, Alaska	Subbituminous C	.57 2/	7.7 3/	22.5	12.3	10
Velva mine lignite, Ward County, N. Dak.	Lignite	13.1 2/	177 3/	93	51	144

1/ Characteristic oxidation rate, the percentage of oxygen consumed per day at 100° C. in air after the coal has consumed 1 percent of its dry, mineral-matter-free weight of oxygen.

2/ The rate of oxidation, percentage of oxygen consumed per day at 100° C. in air after the coal has consumed 5 percent of its dry, mineral-matter-free weight of oxygen. For Pittsburgh bed, Warden mine, this value is 0.074 percent per day.

3/ Ratio of the oxidation rates after the coal has consumed 5 percent of its dry, mineral-matter-free weight of oxygen compared to Pittsburgh bed, Warden mine.

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UTILIZATION OF COAL

Combustion

Fuel-Engineering Service

The Fuel-Engineering Service is a consulting service furnished by Bure engineers to other Federal agencies with respect to the selection and use o fuels and equipment for burning fuels. Special surveys were made at the request of the Navy Department, the Department of Agriculture, the Veterans Administration, the Procurement Division, and a number of Government heating plants in the Washington (D. C.) area. A survey of the new power plant at Patuxent River Naval Station provided information for selecting the proper coal for use in this plant. Operation difficulties caused by the corrosion of tubes in two boilers at the Washington Navy Yard were investigated, and various changes were recommended as temporary measures to insure continued operation. Acceptance tests on new dust collectors and induced-draft fans at the Horticulture Station of the Department of Agriculture at Beltsville, Md., were completed. At the request of the Veterans Administration, efficiency calculations were made for proposed new boiler equipment at Lyons, N. J., and plants at Sheridan, Wyo., and Bowney, Ill., were studied to determine suitable types of stokers. Two heating plants of the Housing Administration in the vicinity of Arlington, Va., were examined to establish the best types of coal, changes in equipment, and operating routi and resulting recommendations were made to the Procurement Division. Prope routine operating practices were recommended at the heating plant of the Columbia Institute for the Deaf. Studies and resulting recommendations wer made on equipment changes at the Capitol Power Plant and at the new power plant at St. Elizabeths Hospital. Investigations of stoker operations, burning of anthracite-bituminous coal mixtures, and possible carry-over of oil into the boiler were conducted at the District Building. Tests were made on a new incinerator in the Government Printing Office. An acceptance test was made of a new boiler feed-water heater at the Glen Dale Sanitarium and necessary changes in operation were recommended. Consulting service was rendered various Government agencies on the analyses of bids and awards for the purchase of fuel and on related matters involving fuel purchases, a affected by war conditions.

Boiler Feed-Water Conditioning

Analyses and resulting recommendations were made for 18,685 samples of water submitted by Federal agencies during the fiscal year. This number w almost triple that of the previous year. A large part of the increase - 17,894 samples in all - was to insure adequate supplies of suitable waters for the War Department. Reports were made on analyses of 7 boiler compounds and 45 boiler scales, sludges, or deposits. Three hundred and ninet nine special Bureau of Mines field boiler-water test kits, 11,361 bottles of chemical reagents, and 10,712 test-kit replacement items were distribute mostly to Army posts in this country and overseas. A simple test kit was developed for determining the causticity of boiler water for boilers being operated overseas by the Army. An investigation was made for the War

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Department on the causes of corrosion in return feed lines at Chanute Field in Illinois. A special research study of this problem is being continued at that field with the cooperation of the War Department. Plant surveys were conducted at the request of Gallinger Hospital, St. Elizabeths Hospital, the Home for Aged and Infirm, the Southwest Health Center, and the Garbage Reduction Plant to solve certain water problems. At the request of the Federal Public Housing Authority, an address on boiler feed-water conditioning was given in New York City before a called meeting of superintendents of various housing projects. Personal instruction in testing boiler water was given to operators at the National Training School for Boys, the Capitol Power Plant, and the District Building. At the request of the Procurement Division specifications for polyphosphates were formulated for use in the General Schedule of Supplies. Several new types of polyphosphates were investigated for possible use in Government plants. Consulting service on various other problems was given to 34 different Government establishments in Washington, D. C., and in 7 States.

Corrosion of steam-heating systems is due primarily to carbon dioxide, which acidifies the condensate. One method of preventing corrosion is to introduce enough amine into the steam to neutralize the acidity. The use of cyclohexylamine for this purpose has been studied both in the laboratory and in an operating system.27/ This amine is quite volatile and leaves the boiler with the steam relatively quickly after it enters with the feedwater. To maintain an alkaline condition continuously in the condensate at traps and heaters, frequent and preferably continuous additions of amine should be made to the system. Losses of the amine occur at vents in the system, quantities of the chemical being found in the vented vapors from the deaerating heater. In a system that is amine-treated all of the carbon dioxide in the steam tends to be fixed in the condensate.

Cyclohexylamine treatment has helped to reduce the return-condensate corrosion in steam-heating systems. The amine probably can inhibit corrosion in the manner peculiar to the nitrogenous bases to which it is related. Although this disadvantage is not unsurmountable, all of the defects in the use of cyclohexylamine in steam systems are due to its excessive volatility.

Smoke Abatement

Work was continued by a committee of the American Society of Mechanical Engineers on the formulation of a model smoke law. Agreements on various sections of the law were reached and assignments made for new work. A joint meeting was held with a subcommittee of the American Society for Testing Materials to coordinate certain features of the work. Consulting service was given representatives of Alexandria, Va., and of Salt Lade City, Utah, in connection with their smoke problems and development of proper methods of control.

27/ Berk, A. A., Observations on the Use of Cyclohexylamine in Steam-Heating Systems: Bureau of Mines Rept. of Investigations 3754, 1944, 42 pp.; abs. Combustion, vol. 16, August 1944, p. 51.

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How to Save Fuel

Widespread demand for practical information that everyone can use in an effective manner to save fuel was met by additional publications[58] of a report which appeared in several other places during the fiscal year 1943.[59]

National Fuel Efficiency Program

Current requirements, estimated production, and distribution of fuels justify a thorough analysis of all factors involved in efficient fuel utilization or of the energy derived from it. Increasing difficulties resulting from the shortage of labor in the production, transportation, and distribution of fuel and from frequent break-downs of overloaded and worn-out equipment have focused direct attention on any and all means that may be used to conserve fuels and to improve their utilization. The National Fuel Efficiency Program was established to meet these objectives. Twelve leading fuel engineers were selected to serve as the National Fuel Efficiency Council. Plans were devised to carry out a fuel-conservation program by volunteer effort on the part of fuel users. These plans included dividing the United States into various areas, each of which is supervised by a volunteer coordinator. As of June 30, 1944, 111 coordinators - outstanding men in their respective communities - had been appointed. These coordinators appoint their own individual advisory councils under whom are 5,000 volunteer "regional engineers." These engineers visit individual fuel-burning plants, obtain pledges of the management to cooperate in the program and to appoint one of their employees as a "waste chaser," and with the waste chaser inspect the plant to determine possible savings. The engineers also supply the plants with "quiz sheets." These short, thought-provoking questions-and-answer sheets were prepared by committees representing the best engineering thought of various industries of all phases of fuel burning and utilization of heat and energy. Subject items, including bibliographies for 20 quiz sheets, have been completed. Paid personnel in district offices at Chicago, Ill., and Indianapolis, Ind., assist the voluntary coordinators in an assigned district to further the general program. Interest in the National Fuel Efficiency Program is being evidenced by requests for talks before various national and local societies and groups in the larger cities. Free publicity on this program has been furnished by two-page advertisements in leading technical publications, as well as by write-ups in popular magazines, industrial "house organs," and press releases. Excerpts from addresses by Bureau of Mines personnel outlining the aims and progress of the National Fuel Efficiency Program were published.[60] The immense value of this broad program for conserving and

58/ Barkley, J. F., Prevent Fuel Waste For War: Factory Management and Maintenance, vol. 101, July 1943, p. 164; Pilbrico Firebox, July-August 1943, p. 11.

59/ Fieldner, A. C., Beltz, J. C., and Fisher, P. L., Annual Report of Research and Technologic Work on Coal Fiscal Year 1943: Bureau of Mines Inf. Circ. 7272, 1944, 58 pp.

60/ Fuel Efficiency Program: Smoke (Official Bull., Smoke Prevention Assoc. America, Inc.), vol. 11, No. 6, June 1944, 2 pp.

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efficiently utilizing our fuel supplies cannot be completely measured. It would be extremely difficult to make individual acknowledgments to all who have contributed to this program. The voluntary cooperation of both industrial and domestic users of fuels has been especially gratifying. Representatives of various industries, commercial plants, technical societies, and Government agencies have contributed their individual and cooperative efforts in making the program a success.

Mixtures of Coal and Oil

Emergency use of mixtures of pulverized coal and fuel oil, popularly called "colloidal fuel," in existing oil-burning equipment would save about one-third the available oil and would reduce the required amount of additional costly coal-burning equipment. Conversion of oil-fired boilers to "colloidal" fuel firing was found to be possible without great change in average boiler-plant construction or appreciable difference in boiler efficiency as compared with use of Bunker C fuel oil.61/ Results are reported on the operation of a typical boiler installation during cooperative tests conducted for 1 month by Bureau engineers and the Atlantic Refining Co. The fuel used was a mixture of 40 percent pulverized bituminous coal by weight and 60 percent No. 6 (Bunker C) fuel oil. No "fixateur" or stabilizer was added, and no particular trouble was experienced in batch mixing of the coal and oil. Operations as affected by increased suctions, pressures and loadings on the pumps, abrasiveness of the fuel, settling of coal from the mixture, and ash deposition in the furnace were studied, and no unsurmountable difficulties were encountered.

Extensive laboratory and field tests on the stability of coal suspensions in fuel oil showed that individual consideration must be given to each installation using this mixed fuel, if satisfactory tests are to be obtained.62/ However, no particular difficulty should be experienced in devising equipment or in routine operating to use efficiently this mixed fuel. The study showed that for practical purposes a sufficiently stable

61/ Barkley, J. F., Burdick, L. R., and Hersberger, A. B., "Colloidal" Fuel Substituted for Oil Fuel: Nat. Petrol. News, Tech. Sec., vol. 35, July 1943, pp. R-304-306. "Colloidal" Fuel for Oil: Steel, vol. 113, July 1943, pp. 98-99, 137-138. "Colloidal" Fuel Tests Show Possibilities as Oil Substitutes: Coal Age, vol. 48, July 1943, pp. 51-53. Tests Reveal Colloidal-Fuel Performance: Power, vol. 87, August 1943, pp. 72-73, 144, 146, 148, 150, abs., Steam Eng., vol. 13, January 1944, pp. 104-107.

62/ Barkley, J. F. Hersberger, A. B., and Burdick, L. R., Laboratory and Field Tests on Coal-in-Oil Fuels: Trans. Am. Soc. Mech. Eng., vol. 66, 1944, pp. 185-196; discussion, pp. 196-198. Tests on Coal-in-Oil Fuels: Power Plant Eng., vol. 48, January 1944, pp. 82-84, 132, 134 136, 138. Abs., Power, vol. 87; December 1943, pp. 178-182; Steam Eng., vol. 13, June 1944, pp. 259-263.

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suspension could be prepared by dispersing 40 percent of coal by weight, ground to pass 98 to 99 percent through a No. 230 sieve, in heavy fuel oil. Careful control of storage and handling temperatures is necessary for best operation. The pumping of coal-in-oil suspensions, particularly from underground storage tanks, requires special attention. The combustion efficiency of coal-in-oil fuel is likely to be slightly less than that of fuel oil; their load-carrying flexibilities are about the same. The report covers technical information and does not take up the varying economic comparison involving relative costs of coal and oil.

Utilization of Small-Size Anthracite

In allocating fuel supplies for the Nation, the Solid Fuel Administration for War found that a growing surplus of small sizes of anthracite at the collieries was hindering the production of much needed domestic-size anthracite. Following a meeting of representatives of the anthracite industry, the Solid Fuels Administration for War, and the Bureau of Mines, a program was initiated to remedy this situation and at the same time to alleviate the general coal shortage through increased uses of anthracite fines. Tests were made at a number of plants on the burning of various mixtures of barley-size (No. 3 Buckwheat) anthracite and slack-size bituminous coal on underfeed stokers. The tests included many made in cooperation with the War Department in boiler plants at military camps in the eastern states, for other Government agencies, and in privately owned plants. A discussion[63] of typical results obtained at several plants was published. Chief advantages found by adding barley anthracite to bituminous slack burned on single-retort stokers were: (1) A reduction of coking troubles caused by certain eastern bituminous coals and (2) a lessening of the air-pressure drop through the fuel bed. At one plant as much as 80 percent of anthracite gave satisfactory operation and carried the required load; at another plant a 50-percent addition gave the best performance. Increasing additions of anthractie resulted in hand-working the fuel bed being reduced. For low-ash bituminous coals, lower percentages of anthracit gave better results; the higher percentages gave less flexibility on load changes and lower ratings. For higher-ash bituminous coals, higher percentages of anthracite could be used satisfactorily in obtaining similar loads. Combustible in the refuse and the fly ash was increased, and the volume of smoke produced was decreased by the use of anthracite. In general, the efficiencies obtained on single-retort stokers with various percentages of added anthracite were about the same as with straight bituminous coal. The better fuel-bed conditions due to anthracite are offset to some extent by the increase of combustible in the ash and refuse. Further details of the results of burning tests of mixtures of anthracite and bituminous coal were published.[64] This paper also presents the technical aspects of this and

63/ Barkley, J. F., Discussion of "The Combustion of Barley Anthracite," by Allen J. Johnson: Trans. Am. Soc. Mech. Eng., vol. 66, 1944, p. 406.

64/ Barkley, J. F., and Seymour, W., The War Problem of Increasing the Utilization of Small Anthracite: Preprint of paper presented at semiannual meeting, Am. Soc. Mech. Eng., Fuels Division, Pittsburgh, Pa., June 20, 1944, 11 pp. (mim.).

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three other projects. These three latter projects are still in progress; they include studies of (1) methods of producing and burning "packaged fuel" made from anthracite fines, (2) use of anthracite fines as a substitute for part of the low-volatile bituminous coal used in coke-oven charges, and (3) use of barley-size anthracite in gas producers.

Supplementing Anthracite with Other Fuels for Home Heating

Studies of emergency fuels for home heating were made under controlled laboratory conditions closely duplicating those occurring in domestic heaters. The fuels tested included reclaimed beehive coke, mixtures of anthracite and bituminous coal, and packaged fuels made from anthracite fines. Suitability of the emergency fuel was determined from the standpoint of rate of burning, draft required, tendency to produce smoke, caking characteristics, and ash content. Domestic consumers unable to obtain their usual supplies of anthracite were advised to substitute bituminous coal in part, and methods of firing the composite fuel were described.65/ Brief summaries of methods for reducing clinker formation and removing soot accumulations were included.

Studies of Packaged Fuel

A report66/ was published that reviewed the status of the packaged-fuel industry as of 1941. A field study was made of 35 representative plants to obtain technical and economic data on the different types of processes used to make packaged fuel in the Central States. The report includes a classification of processes, photographs of typical operations, designs of different plants, an analysis of costs of manufacture, and a study of the physical and chemical properties of the fuel cubes or bricks. As distinguished from fuel briquets, packaged fuel, although briquetted, is wrapped in paper and differs in methods of manufacture and handling and in shape and size. It is generally made in relatively smaller plants located near the ultimate consumer, and more care must be used in its handling and distribution than with fuel briquets. These fundamental differences between the two types of briquetted fuel are reflected in the costs and economics of the two industries. Many of the packaged-fuel plants had trouble in competing with lump coal under the conditions of costs of materials and labor existing in 1941-42. Predominant technical difficulties in plants were found to be due to inadequate drying and insufficient mixing of the binder. Laboratory studies showed the relationship between the temperature of dry air and the time required to remove different percentages of moisture in wrapped and unwrapped coal cubes. The average physical and chemical properties of fuel cubes made by five processes were determined. Tentative standards for minimum physical qualities and methods for measuring quality were suggested. A satisfactory packaged fuel, air-dried to about 1.0 percent moisture content, should have an average compressive strength of not

65/ Reid, W. T., Supplementing Anthracite with Other Fuels for Home Heating: Bureau of Mines Inf. Circ. 7260, 1943, 22 pp.

66/ Parry, V. F., Technical and Economic Study of Packaged Fuel: Bureau of Mines Rept. of Investigations 3757, 1944, 45 pp; Min. Cong. Jour., vol. 30, November 1944, pp. 24-27.

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less than 85 pounds per square inch and an apparent specific gravity of not less than 1.04, and the average abrasion loss in a modified tumbler test for coal should not exceed 15.0 percent. Packaged fuel has proved to be a satisfactory domestic fuel in many cities. Considerable expansion of possible market is indicated for good, solid cubes delivered in clean, dry packages, even at premium prices above that of lump coal delivered in bulk. The fuel has been particularly popular for spring and fall heating. Some changes in firing technique with no distrubance or poking until the cube has been thoroughly heated and coked on the outside were recommended.

Automatic Stoker for Heating Water

A new-type stoker and heater for supplying hot water automatically was developed and tested. The unit has operated satisfactorily for 2-1/2 years, with a consumption of about 300 pounds of selected coal a month. Several grades of subbituminous coal have been burned successfully, with a thermal efficiency of about 71 percent.

Properties of Coal Ash as Related to Clinkering and Slagging

Data not previously available on the flow properties of coal-ash slags below the temperature where crystals separate from the melt on cooling were obtained in a recent study.67/ The conventional concentric-cylinder viscometer used in a previous study was modified to include a motor drive; a reducing atmosphere was used to control the oxidation of iron forms in the slag. The study showed that the "temperature of critical visosity," where the flow of slag changes abruptly from liquid to plastic flow on slow cooling, was affected in a complex manner by change in composition and state of reduction of the forms of iron present. For a given state of oxidation, the temperature of critical viscosity, T_{cv}, decreased as the equivalent ferric oxide content of the slag increased, this being greatest for small amounts of calcium oxide. For a fixed ferric oxide content, increasing calcium oxide also decreased T_{cv}. Decrease in the ferric percentage lowered T_{cv} most as the equivalent ferric oxide content of the slag increased. Similar complex relationships were found to exist for the freezing temperature of coal-ash slags. The viscosity-temperature relationship at temperatures high enough for the slags to be completely in the liquid state was represented by the equation:

$n^z = A\,t - B$, where n is viscosity in poises, z is 0.1614, A is 0.000459, t is degrees Fahrenheit, and B is a constant depending on the composition of each slag. Figure 5 is a nomogram based on this relationship; it allows estimation of the viscosity of coal-ash slags at any temperature above T_{cv}. Application of determined data in predicting the relative thickness of various slag deposits, although based on idealized furnace conditions, will prove useful in proposed field studies of the action of coal-ash slag in furnaces. A recent paper68/ was published giving complete details of this

67/ Reid, W. T., and Cohen, P., The Flow Characteristics of Coal-Ash Slags in the Solidification Range: Am. Soc. Mech. Eng., Furnace Performance Factors (pamphlet), May 1944, pp. 83-97.

68/ Cohen, P., and Reid, W. T., The Flow of Coal-Ash Slag on Furnace Walls: Bureau of Mines Tech. Paper 663, 1944, 22 pp.

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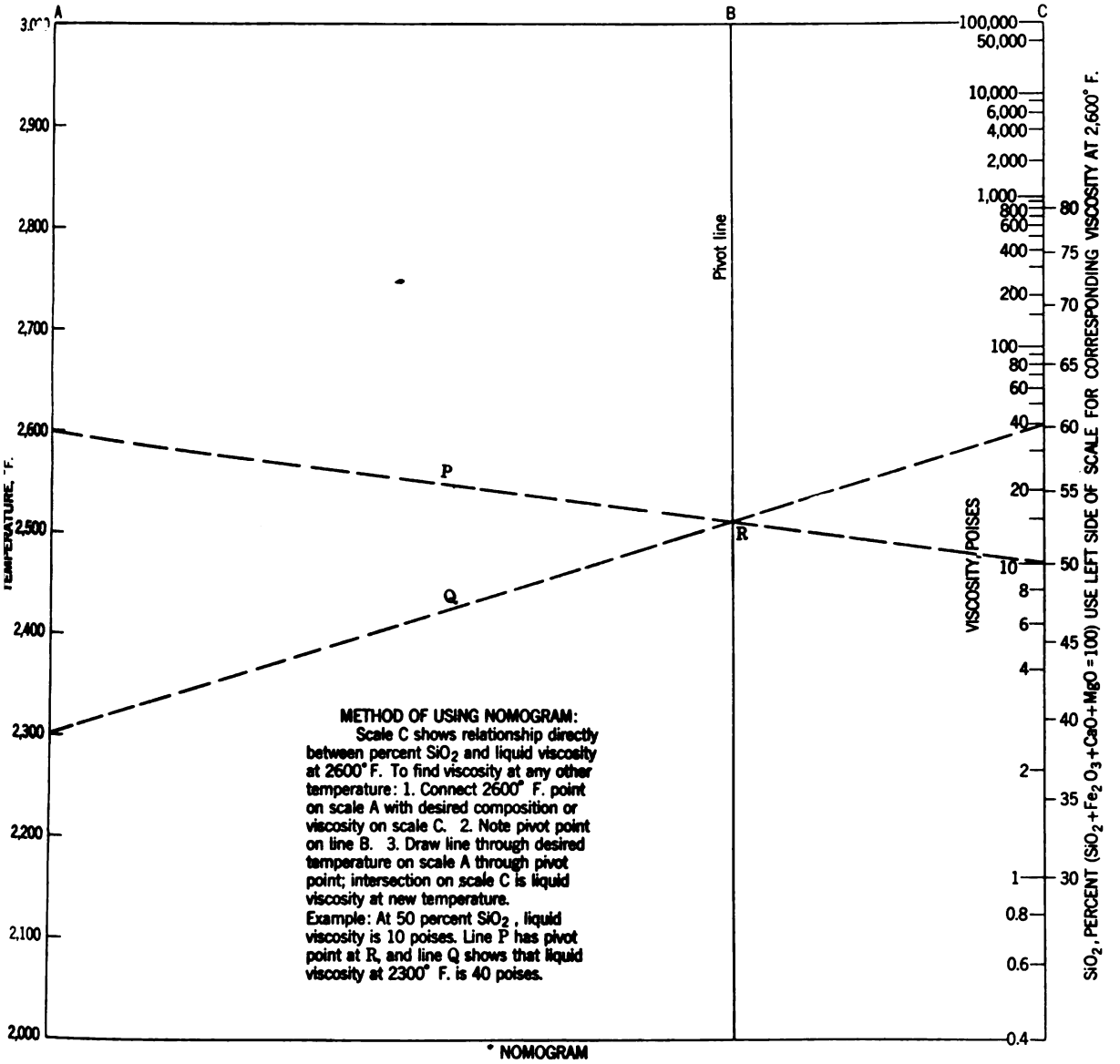

FIGURE 5.- Viscosity of coal-ash slags in the liquid state as a function of composition and temperature.

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method for calculating the thickness of slag deposits and illustrations were given of its application to slagging furnaces. A field study on the action of coal ash in boiler furnaces has been planned in cooperation with the Special Research Committee on Furnace Performance Factors of the American Society of Mechanical Engineers.

Thermal Conductivity of Coal-Ash Slags

Methods have been suggested[69] whereby the physical condition of the slag deposit can be used as a rough measure of the rate of heat transfer through the slag. Direct measurements of this factor would be preferable but suitable devices for measuring the rate of heat transfer to slagged surfaces in operating furnaces must be used with forethought as to their design and location in the furnaces.[70] In the problem of heat transfer from the furnace cavity to the tube metal, allowance must be made for the thermal conductivity of the slag and the thermal resistance of the interfacial layer of loose ash between the tube metal and the slag. This thermal resistance is difficult to measure. The thermal conductivity of the slag itself can be measured directly in the laboratory under controlled conditions and the results applied to field tests to determine the over-all conductivity of the deposit.

In cooperation with the Furnace Performance Factors Committee of the American Society of Mechanical Engineers, a laboratory investigation of the thermal conductivity of coal-ash slags at high temperatures was begun. Apparatus has been designed and tests have been started to measure the thermal conductivity for temperatures ranging from 1,800° to 2,800° F. and for compositions representative of normal coal-ash slags.

External Corrosion of Furnace-Wall Tubes

The mechanism of reactions causing external corrosion of furnace-wall tubes was investigated further. The mode of formation of the greenish white "enamel" found in or adjacent to corrosion areas was studied by comparison with synthetically produced material whose composition was identified by X-ray diffraction analysis. Under certain conditions the enamel was shown to be highly corrosive. Attempts to measure by radiometric methods the temperature of the thin oxide film occurring on the surface of the furnace-wall tubes showed that certain important considerations must be given to the use of optical and total radiation pyrometers.[71] The study showed that under

69/ Reid, W. T., Discussion of "Studies of Heat Transmission Through Boiler Tubing at Pressures from 500 to 3300 Pounds," by W. F. Davidson and others: Trans. Am. Soc. Mech. Eng., vol. 65, 1943, pp. 589-590.

70/ Reid, W. T., Discussion of "Distribution of Heat Absorption and Factors Affecting Performance of Twin Branch 2,500-Psi Boiler" by F. G. Ely, and L. B. Schueler: Am. Soc. Mech. Eng., Furnace Performance Factors (pamphlet), May 1944, pp. 30-31.

71/ Reid, W. T., and Corey, R. C., Errors in Temperature Measurements by Radiometric Methods: Combustion, vol. 15, February 1944, pp. 30-34.

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conditions where the object has a temperature lower than the surroundings, as in the case of furnace tubes absorbing heat, small variations in emissivity radically affect the temperature observed by the optical pyrometer but have appreciably less effect on the total radiation pyrometer. Tables showing the apparent temperatures of cold objects surrounded by an environment at 2,700° F. were provided to show comparisons between the two types of instruments.

Burning Solid Fuels on Traveling Grates

Tests of the burning characteristics of various ranks of coal on traveling- or chain-grate stokers were continued with a high-volatile C bituminous coal from Illinois and a raw lignite from North Dakota.

Less variation in rate of ignition travel was observed with change of size of the high-volatile C bituminous coal than had been found with higher-rank coals and coke. Ignition rates were relatively high over a very wide range of air rates, but they showed a tendency to decrease at 600 pounds per square foot per hour and higher air rates. Less difficulty was experienced with caking and poor-air distribution at the lower air rates than had been found previously with more highly caking Pittsburgh-bed, high-volatile A bituminous coal. At air rates of 400 pounds per square foot per hour and higher, ignition and burning were obtained with relatively little caking.

With lignite, no gain in rate of ignition travel was indicated for the use of air rates exceeding 250 pounds per square foot per hour for the raw lignite, although no sharp drop in ignition rate is indicated at air rates up to 600 pounds. This is a very reactive fuel and burns with very thin burning layers. Excessive loss of heat from such burning layers, as when exposed to cold furnace walls, will materially reduce the rate of ignition and burning in such thin layers. Highest ignition and burning rates would therefore be expected with this fuel in refractory-lined furnaces with walls at high temperature.

Reactivity of Solid Fuels by the Ignition-Point Method

Reactivity of various solid fuels was measured in the ignition-point apparatus. Minor improvements were made in the apparatus, but most of the work was directed toward determining the limitations of the method and its application to fuel-burning problems. If the entire sample of the coal was included, the rate of reaction at a given temperature was found to be proportional to the specific surface. With rejection of small sizes, this relationship may not hold. Study of the burning of fuels on open grates showed that the time required to reach the maximum burning rate or the quantity of fuel burned the first hour could be predicted from the ignition-point method. Factors other than external surface and reactivity, such as the porosity of the fuel, affected the burning rates of different types of fuels when burned under comparable conditions.

Stability and Structure of Burner Flames

The principles governing the attachment of flames to burner ports were studied. It was found that blow-off and flash-back limits of gas flow can

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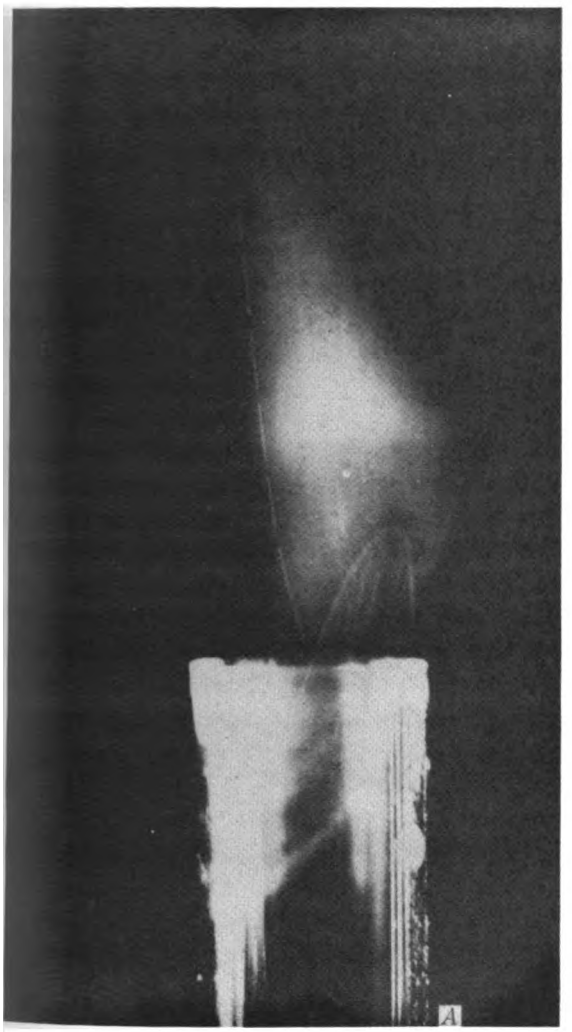

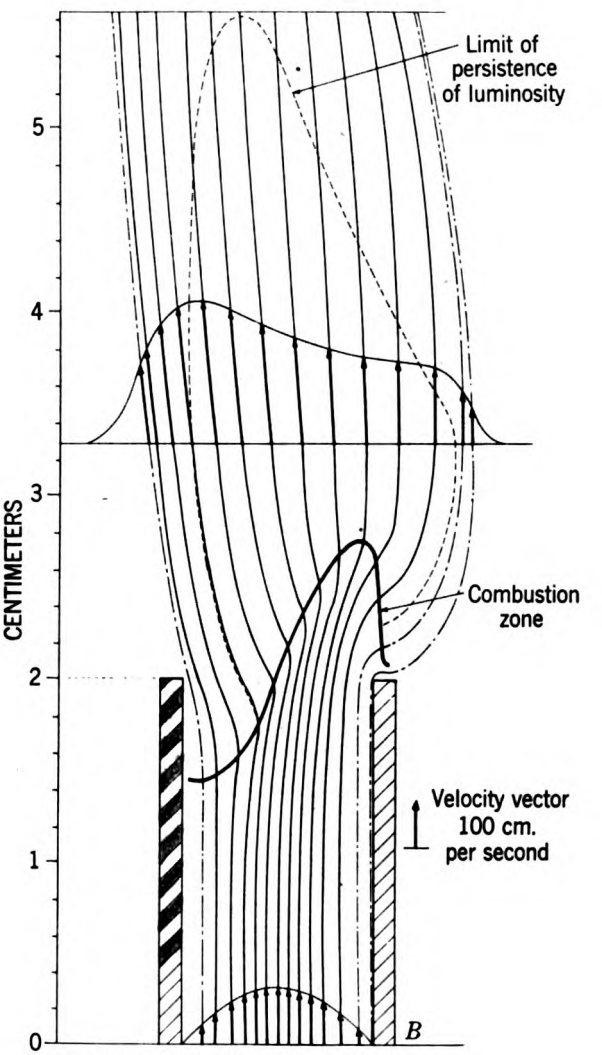

FIGURE 6.- Flame of natural gas and air, partly drawn into burner tube at gas flow just exceeding critical flow for flashback. Mixture composition, 8.1 percent natural gas in air; gas flow, 52 c.c. per second; inside diameter of tube, 1.068 cm. A, Photograph with particle tracks in vertical center plane (see Lewis and von Elbe, work cited). B, Diagram of flow pattern and velocity distribution. Solidly drawn flow lines are so located that the mass flow between any two adjoining lines is the same.

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be calculated for any burner tube from a knowledge of only two constants which are specific for the gas mixture and which represent critical gradients of gas velocity at the stream boundary. Flames of natural gas and air, of hydrogen with air and oxygen, and of acetylene with oxygen were investigated. The latter are among the hottest and fastest-burning known, while natural-gas-air flames are comparatively cool and have very-low-burning velocities. The data extend over an extreme range of conditions, and the existence of two critical boundary velocity gradients has been verified for all cases. In addition, the relationships that govern the formation of tilted flames, such as the flame shown in figure 6, have been investigated. Flames of this type are characterized by dynamic asymmetry of the effluent gas stream and consequent distortion of the flow pattern, permitting partial entrance of the combustion zone into the burner tube. Since such flames are generally unstable, their formation places a further limitation on the range of usable flames. A generally applicable equation has been found which permits calculation of the range of gas flow over which burner flames tend to become tilted.

The mechanism of flame propagation has been clarified, and a difficulty of long standing concerning the stability of a combustion zone in a gas stream has been resolved. The dynamics of the thermal expansion of the gas in burner flames has been developed. The quantitative relation between the pressure of the gas stream in the burner tube, the burning velocity, and gas density has been verified experimentally. Finally, it has been demonstrated that quantitative relations exist between the critical boundary velocity gradient for flash-back, the limiting tube diameter for flame propagation and the limiting electrode distance for electric spark ignition. These relations have been derived from consideration of the depth of penetration of the quenching of explosive reactions by solid surfaces.

Carbonization and Gasification

The main objectives of the work for the fiscal year were: Proving of new or imperfectly known reserves of coking coals, finding new methods of using available coals, estimating the storage properties of coals, and determining the yields or tar oils with a view to possible increased utilization of the neutral oils as fuel and the tar acids in the manufacture of plastics.

Coals received for complete series of tests were: (1) Eagle-bed bituminous coal from Kanawha County, W. Va., (2) Powellton-bed bituminous coal from the same location, (3) Elkhorn No. 3-bed bituminous coal from Floyd County, Ky., (4) Monarch-bed subbituminous coal from Sheridan County, Wyo., and (5) Velva mine lignite from Ward County, N. D. The Eagle-, Powellton-, and Elkhorn-bed coals rank as high-volatile coking coals; Elkhorn coal has a dry, volatile-matter content of 39.6 percent and would also be classified as a gas coal. All three coals contain low sulfur and low ash and are satisfactory in this respect for making coke and gas. The Eagle and Powellton coals are hoisted from the same shaft and loaded at the same tipple. Tests of these two coals showed that they could be mixed at the mine and the mixture used for coking purposes. The main objective in the tests of Elkhorn-bed coal was to determine whether a more readily available

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Beckley-bed, low-volatile bituminous coal could be substituted for the Pocahontas No. 3-bed, low-volatile bituminous coal regularly used in blends with the Elkhorn coal. Because the Beckley-bed coal varies in expanding properties, depending upon its location in the various mines, the expanding properties of 17 different samples of Beckley-bed coal were determined. The Monarch-bed subbituminous coal produced char on carbonization, instead of coke. However, the ash and sulfur contents were low, and the char should be satisfactory in metallurgical processes where a true coke is not required. This char has been proposed for use in the manufacture of sponge iron. The ash content of the Velva lignite on the dry basis was 11.9 percent and that of its char 15.0 percent. The sulfur content was only 0.3 percent. It was proposed to process this lignite for production of solid fuel and tar oils.

Table 4 gives the yields of carbonization products at 900° C., obtained on the as-carbonized basis by Bureau of Mines - American Gas Association (BM-AGA) 18-inch retort tests, for high-volatile A bituminous Eagle-bed and Elkhorn No. 3-bed coals, and for blends of these coals with low-volatile bituminous Pocahontas No. 3-bed coal, for a 50:50 blend of high-volatile Eagle-and Powellton-bed coal, for subbituminous Monarch-bed coal, and for Velva lignite. The volatile matter, on the as-carbonized basis, was 32.7 percent for the Eagle coal and 38.5 percent for the Elkhorn coal. The corresponding ash contents were 7.4 and 3.0 percent, respectively. Therefore, Eagle should yield more coke and less volatile products than Elkhorn coal, as is shown in table 4. When the Eagle coal was blended with an equal quantity of Powellton coal, which contained 33.1 percent volatile matter and 2.0 percent ash on the as-carbonized basis, the yield of gas was raised from 10,500 to 11,000 cubic feet per ton, the yield of tar was increased from 12.6 to 13.6 gallons per ton, and the yield of coke was decreased from 72.1 to 71.1 percent. The Monarch subbituminous coal yielded somewhat less coke and considerable more tar than were obtained in a similar earlier test of Puritan mine subbituminous coal from Weld County, Colo. The Velva as-received lignite contained 37.0 percent moisture. Before it could be carbonized at 900° C. in the 18-inch retort, it was necessary to dry the lignite to a moisture content of 10 percent. The yields of carbonization products shown in table 4 are on that basis. The yields of tar and light oil from the dried product are very low, and the volume yield of gas is quite high. The high yield of gas results from reaction of the moisture remaining in the coal with the char being produced, and perhaps also with the tar products, to form water gas. Table 5 shows the yields of carbonization products obtained at 500° C. in 13-retort tests from the original lignite and from two dried products. At 500° C. the water-gas reaction is not appreciable. The advantage of drying the lignite before carbonization is shown by the increased yields of valuable products, such as coke, gas, tar, and light oil. It is believed that these yields represent approximately those to be expected by batch carbonization of dried lignite at low temperatures.

Table 6 gives the analyses of the cokes and chars. The granular char from the lignite is high in ash and probably would require briquetting for satisfactory use as domestic fuel. Both the lignite and subbituminous coal chars are high in volatile matter. The fact that the cokes and chars all have about the same hydrogen and total carbon contents, if expressed on a dry, ash-free basis, indicates that the excess volatile matter in the chars contains but little combustible carbon.

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Coal 82 - 100 percent Eagle bed
Coal 82A - 80 percent Eagle bed and 20 percent Pocahontas No. 3 bed (coal 75)
Coal 82B - 70 percent Eagle bed and 30 percent Pocahontas No. 3 bed (coal 75)
Coal 82C - 50 percent Eagle bed and 50 percent Powellton bed (coal 83)
Coal 84 - 100 percent Velva lignite
Coal 85 - 100 percent Monarch bed
Coal 86 - 100 percent Elkhorn No. 3 bed
Coal 86A - 80 percent Elkhorn No. 3 bed and 20 percent Pocahontas No. 3 bed (coal 75)
Coal 86B - 70 percent Elkhorn No. 3 bed and 30 percent Pocahontas No. 3 bed (coal 75)

(Carbonization tests at 900° C.)

Coal No.	Retort diameter, inches	Yields, percent by weight of coal[1]							Yields per ton of coal[1]				
		Coke	Gas	Tar	Light oil	Free ammonia	Liquor	Total	Gas, cubic feet	Tar, gallons	Light oil, gal. In gas	Light oil, gal. To 170° C.	$(NH_4)_2SO_4$, pounds
82	18	72.1	14.1	6.2	1.08	0.213	4.7	98.4	10,500	12.6	2.97	.45	20.9
82A	18	74.3	13.4	5.4	1.03	.207	4.5	98.8	10,500	11.0	2.84	.53	20.8
82B	18	75.6	13.2	4.7	.94	.202	4.5	99.1	10,400	9.7	2.62	.54	19.6
82C	18	71.1	14.7	6.8	1.13	.219	4.7	98.7	11,000	13.6	3.11	.57	20.8
84[2]	18	53.4	37.9	.4	.28	.062	7.3	99.3	18,200	.8	.76	.06	12.9
85	13	44.8	23.1	2.6	.88	.021	25.9	97.3	11,850	5.8	2.44	.88	24.3
86	18	66.4	16.1	7.4	1.28	.158	7.7	99.0	10,850	15.4	3.57	2.11	26.8
86A	18	69.5	14.7	6.4	1.01	.158	7.1	98.9	10,350	13.7	2.87	2.15	24.5
86B	18	71.3	13.8	6.1	.96	.162	6.9	99.2	10,250	13.0	2.73	2.07	23.7

1/ Coke, tar, ammonia, and light oil are reported moisture-free; gas is reported as stripped of light oil and saturated with water vapor at 60° F. and under a pressure of 30 inches of mercury.
2/ Dried to 10-percent moisture content before carbonization.

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TABLE 5. - Yields of carbonization products from Velva lignite, as-carbonized basis

(Carbonization tests at 500° C. in 13-inch retort)

Test No.	Moisture, percent	Yields, percent by weight of coal[1]							Yields per ton of coal[1]				
		Coke	Gas	Tar	Light oil	Free ammonia	Liquor	Total	Gas, cubic feet	Tar, gallons	Light oil, gal.		$(NH_4)_2SO_4$, pounds
											In gas	Tar to 170° C.	
84-1	37.0	46.6	5.9	1.1	0.15	0.007	40.5	94.3	2,050	2.5	0.45	0.06	6.8
84-9	8.0	69.2	11.9	2.1	.21	.007	12.7	96.1	3,250	5.1	.63	.19	9.4
84-13	6.5	70.8	11.8	2.1	.22	.012	10.9	95.8	3,300	5.0	.65	.20	9.3

1/ Coke, tar, ammonia, and light oil are reported moisture-free; gas is reported as stripped of light oil and saturated with water vapor at 60° F. and under a pressure of 30 inches of mercury.

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TABLE 6. - Analysis of coke and char, dry basis

Coal 82 - 100 percent Eagle bed.
Coal 82A - 80 percent Eagle bed and 20 percent Pocahontas No. 3 bed (coal 75)
Coal 82B - 70 percent Eagle bed and 30 percent Pocahontas No. 3 bed (coal 75)
Coal 82C - 50 percent Eagle bed and 50 percent Powellton bed (coal 83)
Coal 84 - 100 percent Velva lignite
Coal 85 - 100 percent Monarch bed
Coal 86 - 100 percent Elkhorn No. 3 bed
Coal 86A - 80 percent Elkhorn No. 3 bed and 20 percent Pocahontas No. 3 bed (coal 75)
Coal 86B - 70 percent Elkhorn No. 3 bed and 30 percent Pocahontas No. 3 bed (coal 75)

(Carbonization tests at 900° C.)

Coal No.	Retort diameter, inches	Proximate, percent		Ultimate, percent						Heating value, B.t.u. per lb.
		Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	
82	18	1.0	88.8	10.2	0.6	87.0	1.3	0.2	0.7	12,950
82A	18	.9	89.8	9.3	.6	87.9	1.2	.3	.7	13,040
82B	18	1.0	90.0	9.0	.6	88.2	1.2	.2	.7	13,170
82C	18	.8	92.5	6.7	.6	90.7	1.3	.1	.6	13,460
84 1/	18	3.8	76.7	19.5	.7	77.6	.4	1.5	.3	11,610
85	13	3.0	87.8	9.2	.8	87.8	.9	.8	.5	13,130
86	18	1.9	93.6	4.5	.6	91.9	1.5	.8	.7	13,730
86A	18	2.4	92.4	5.2	.5	91.2	1.3	1.0	.8	13,660
86B	18	2.0	92.3	5.7	.5	91.0	1.3	.8	.7	13,650

1/ Dried to 10-percent moisture content before carbonization.

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Table 7 shows the physical properties of the cokes. The chars from the lignite and subbituminous coal were not fused, so that the usual standard tests for physical characteristics could not be made. The fresh lignite char was very sensitive to spontaneous heating. Compared with the more significant indexes of the measurable physical properties that have been averaged for cokes produced from 25 high-volatile coals previously tested, the Eagle coal shows an average 1 1/2-inch shatter index, lower 1-inch and 1/4-inch tumbler indexes, and higher apparent specific gravity. The 50:50 blend of Eagle and Powellton coals produced a weaker coke of higher apparent specific gravity, and coke from the Elkhorn coal is inferior by all indexes, as compared with the average indexes of the 25 cokes.

Table 8 shows the physical and chemical properties of the gas. Judged by the yield of gas expressed in terms of British thermal units per pound of coal carbonized, the yields of gas from Eagle coal and from the five blends containing low-volatile Pocahontas No. 3 coal are about normal. The yield of gas from Elkhorn is higher and is characteristic of other Elkhorn coals tested. The high CO content in the gas from the lignite and the subbituminous coal resulting from the water-gas reaction at the 900° C. carbonization temperature accounts for the seemingly high B.t.u. per pound of coal values for the gases from these low-rank coals.

Table 9 gives analyses of the tar distillates and light oils. The composition of the tars and light oils from the two high-volatile coals and their blends is normal for coals of their ranks. The lignite and subbituminous coal are characterized by high-tar acid content. The high-toluene and low-benzene contents of the light oil from the lignite is noteworthy; apparently the toluene was protected from decomposition by the presence of excess moisture and water gas.

Carbonizing Properties of American Coals

Studies of the carbonizing properties, plasticity, expansion, effect of oxidation, and deterioration in storage of bituminous coking coals were continued. The work of the survey of carbonizing properties of American coals from its inception in 1928 through 1944 has been briefly outlined in a recent report.72/ This report brings the index of coals tested by the Bureau of Mines-American Gas Association (BM-AGA) method up to date, discusses the development of auxiliary tests, and outlines the uses to which the methods have been put in promoting the war program. Up until 1942 the test methods developed with the advice of the Advisory Committee of the American Gas Association had been applied to 66 coals. The present paper gives the sources and analyses of 20 additional coals.

72/ Davis, J. D., and Reynolds, D. A., Work of the Survey of Carbonizing Properties of American Coals: Bureau of Mines Rept. of Investigations 3760, 1944, 17 pp.

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TABLE 7. - Physical properties of cokes

Coal 82 - 100 percent Eagle bed
Coal 82A - 80 percent Eagle bed and 20 percent Pocahontas No. 3 bed (coal 75)
Coal 82B - 70 percent Eagle bed and 30 percent Pocahontas No. 3 bed (coal 75)
Coal 82C - 50 percent Eagle bed and 50 percent Powellton bed (coal 83)
Coal 86 - 100 percent Elkhorn No. 3 bed
Coal 86A - 80 percent Elkhorn No. 3 bed and 20 percent Pocahontas No. 3 bed (coal 75)
Coal 86B - 70 percent Elkhorn No. 3 bed and 30 percent Pocahontas No. 3 bed (coal 75)

(Carbonization tests at 900° C. in 18-inch retort)

Coal No.	True specific gravity	Apparent specific gravity	Cells, percent	Shatter test, cumulative percent upon-				Tumbler test, cumulative percent upon-			
				2-inch screen	1-1/2-in. screen	1-inch screen	1/4-inch screen	2-inch screen	1-1/2-in. screen	1-inch screen	1/4-inch screen
82	1.87	0.93	50.3	50.1	71.9	88.4	97.2	0.6	11.9	40.1	65.5
82A	1.89	.93	51.0	49.8	76.8	91.5	97.9	2.4	17.5	47.3	71.2
82B	1.88	.91	51.8	57.6	81.7	93.2	97.9	3.1	21.5	51.3	70.5
82C	1.85	.92	50.2	40.1	66.5	89.5	98.0	.0	11.2	47.0	70.1
86	1.86	.76	59.0	28.1	53.5	79.5	98.0	.0	4.4	34.6	74.4
86A	1.88	.80	57.2	47.4	75.3	92.1	98.3	4.0	25.1	57.2	74.6
86B	1.80	.83	53.9	25.3	74.5	92.3	98.8	5.4	25.1	59.2	71.5

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TABLE 8. - Physical and chemical properties of gas

Coal 82 - 100 percent Eagle bed
Coal 82A - 80 percent Eagle bed and 20 percent Pocahontas No. 3 bed (coal 75)
Coal 82B - 70 percent Eagle bed and 30 percent Pocahontas No. 3 bed (coal 75)
Coal 82C - 50 percent Eagle bed and 50 percent Powellton bed (coal 83)
Coal 84 - 100 percent Velva lignite
Coal 85 - 100 percent Monarch bed
Coal 86 - 100 percent Elkhorn No. 3 bed
Coal 86A - 80 percent Elkhorn No. 3 bed and 20 percent Pocahontas No. 3 bed (coal 75)
Coal 86B - 70 percent Elkhorn No. 3 bed and 30 percent Pocahontas No. 3 bed (coal 75)

(Carbonization tests at 900° C.)

Coal No.	Retort diameter, inches	Specific gravity	Gross heating value[1]: B.t.u. per cubic foot, Determined	Gross heating value[1]: B.t.u. per cubic foot, Calculated	Gross heating value[1]: B.t.u. per pound of coal	H_2S, grains per 100 cubic feet	Composition, dry, percent by value: CO_2	Illuminants	O_2	H_2	CO	CH_4	C_2H_6	N_2
82	18	0.357	602	590	3,160	300	1.4	4.5	0.3	55.1	5.2	31.3	0.9	1.3
82A	18	.339	581	569	3,050	250	1.7	3.7	.3	57.3	4.9	29.8	1.0	1.3
82B	18	.336	566	556	2,940	230	1.7	3.3	.3	59.0	4.5	29.0	.8	1.4
82C	18	.356	597	587	3,280	240	1.2	4.3	.3	55.4	5.1	32.3	.4	1.0
84[2]	18	.554	331	329	3,010	30	12.9	.5	.2	47.6	28.2	6.8	.7	3.1
85	13	.517	450	440	2,680	150	12.8	2.3	.4	47.8	16.1	19.0	.7	.9
86	18	.393	610	603	3,310	330	2.4	5.2	.3	50.6	7.4	31.4	1.5	1.2
86A	18	.377	600	582	3,110	320	2.2	4.1	.4	54.6	6.2	28.6	2.3	1.6
86B	18	.359	586	576	3,000	300	1.9	4.1	.3	55.9	5.7	29.0	1.6	1.5

1/ Stripped of light oil and saturated with water vapor at 60° F. and under a pressure of 30 inches of mercury.
2/ Dried to 10-percent moisture content before carbonization.

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TABLE 9. - Analysis of tar distillate and light oil

Coal 82 - 100 percent Eagle bed
Coal 82A - 80 percent Eagle bed and 20 percent Pocahontas No. 3 bed (coal 75)
Coal 82B - 70 percent Eagle bed and 30 percent Pocahontas No. 3 bed (coal 75)
Coal 82C - 50 percent Eagle bed and 50 percent Powellton bed (coal 83)
Coal 84 - 100 percent Velva lignite
Coal 85 - 100 percent Monarch bed
Coal 86 - 100 percent Elkhorn No. 3 bed
Coal 86A - 80 percent Elkhorn No. 3 bed and 20 percent Pocahontas No. 3 bed (coal 75)
Coal 86B - 70 percent Elkhorn No. 3 bed and 30 percent Pocahontas No. 3 bed (coal 75)

(Carbonization tests at 900° C.)

Coal No.	Retort diameter, inches	Distillate, percent by volume of dry tar			Neutral tar oil, percent by volume			Refined light oil from gas, percent by volume				Olefins in crude light oil from gas, percent by volume
		Acids	Bases	Neutral oils	Olefins	Aromatics	Paraffins and naphthenes	Benzene	Toluene	Paraffins	Solvent naphtha	
82	18	3.9	2.1	28.0	8.2	90.9	0.9	67.1	20.0	4.5	8.4	11.7
82A	18	3.9	1.6	26.3	8.6	88.8	2.6	68.7	20.5	4.4	6.4	11.4
82B	18	5.8	1.8	29.6	8.5	86.2	5.3	62.8	20.7	6.3	10.2	13.2
82C	18	3.8	1.4	23.0	6.8	90.6	2.6	70.1	18.7	3.3	7.9	10.6
84 1/	18	9.2	2.5	38.3	13.0	62.2	24.8	46.3	30.4	3.2	20.1	20.5
85	13	17.9	3.7	40.0	14.0	75.9	10.1	64.3	19.0	4.4	12.3	16.8
86	18	7.8	2.1	32.8	11.0	84.3	4.7	67.6	17.1	7.6	7.7	13.6
86A	18	12.9	2.3	37.2	10.0	83.7	6.3	55.7	20.3	11.6	12.4	17.8
86B	18	14.0	2.1	37.1	10.0	81.4	8.6	53.4	19.1	13.8	13.7	20.4

1/ Dried to 10-percent moisture content before carbonization.

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The carbonizing properties and petrographic composition of Thick Freepo bed coal from Harmar mine[73] were determined. The columnar sample for micr scopic studies and the 3,000-pound sample for carbonization tests were take from the same part of the mine, where the bed was 85.5 inches thick. From bo of these samples, 13.5 inches of roof coal, which was not being mined becaus its high-sulfur content, and 12.5 inches of bony coal dividing the two bench were excluded. The columnar sample contained 96 percent bright coal and 3.0 percent fusain; anthraxylous components predominated. The carbonization sam contained 35.3 percent volatile matter, 2.8 percent moisture, 6.3 percent ash and 1.2 percent sulfur upon the as-carbonized basis and 61.7 percent fixed ca bon upon the dry, mineral-matter-free basis. The heating value was 14,860 B.t.u. per pound on the moist, mineral-matter-free basis. The coal therefore ranks as high volatile A bituminous. The ash softened at 2,300° F. The fria bility of the coal, as represented by the carbonizing sample, was 32.3 percent and the agglutinating value index was 7.1 for the 15:1 ratio of silicon carbide to coal. The maximum fluidity, 300 dial divisions per minute by the Gieseler plastometer test, was low for a high-volatile A bituminous coal. The yields of carbonization products were normal for a coal of this rank. Blending with 20 and 30 percent of low-volatile No. 4-bed coal increased the yield of coke and decreased the yields of gas, tar, and light oil but did not affect the yield of ammonium sulfate appreciably. The strength of the cokes was also increased by blending. Similar trends were obtained by blending with 25 percent of low-volatile Pocahontas No. 3-bed coal and with 20 percent of low-volatile Eureka coal from the Lower Kittanning bed. Thick Freeport-bed coal contracted 6.1 percent in the sole-heated oven during carbonization at an average calculated bulk density of 55.5 pounds per cubic foot. Coal from the top bench in the mine contracted 11.8 percent, and that from the bottom bench expanded 0.6 percent. Oxidation of Thick Freeport coal in air at 99.3° C. for 4.0, 9.1, 13.0, and 22.1 days progressively loweredthe yield of tar at 800° C. but did not affect the strength of coke until the period of oxidation exceeded 9.1 days. The proportion of aromatic constituents in the neutral tar oil was increased and those of paraffins and naphthenes were decreased; simultaneously, the proportion of light oil was increased.

The composition and carbonizing properties of nine coals from the Western Region Interior Province and certain blends of these coals were investigated.[74] These coals included: Henryetta bed, Atlas No. 2 mine, Okmulgee County, Okla.; Bevier bed, No. 18 mine, Cherokee County, Kans.; McAlester Bed, Dow No. 10 and Bernard mines, Pittsburg County, Okla.; Stigler bed, Garland mine, Haskell County, Okla.; Hartshorne Bed, Great Western and Quality mines, Sebastian County, Ark.; No. 17 mine LeFlore County, Okla.; and Hartshorne bed, San Bois No. 14 mine, Haskell County, Okla. The Hartshorne beds were not identified as Upper or Lower Hartshorne

73/ Davis, J. D., Reynolds, D. A., Sprunk, G. C., Holmes, C. R., and McCartney, J. T., Carbonizing Properties and Petrographic Composition of Thick Freeport-Bed Coal from Harmar Mine, Harmarville, Allegheny County, Pa., and the Effect of Blending This Coal With Pocahontas No. 3- and No. 4-Bed Coals: Bureau of Mines Tech. Paper 655, 1943, 46 pp.

74/ Davis, J. D., Reynolds, D. A., Elder, J. L., Ode, W. H., Holmes, C. R., and McCartney, J. T., Carbonizing Properties of Western Region Interior Province Coals and Certain Blends of These Coals: Bureau of Mines Tech. Paper 667, 1944, 138 pp.

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because the information available did not warrant positive identifi-
n at the mines. The first three of these coals were carbonized at 500°,
700°, 800°, 900°, and 1,000° C. McAlester (Bernardi mine), Stigler,
artshorne (San Bois No. 14 mine) coals were carbonized at 900° and
° C. Carbonization tests also were made at 900° C. of 80:20 and 70:30
s of coal from (1) Atlas No. 2 and Great Western mines, (2) Atlas No.
. Quality mines, (3) Bevier-bed and low-volatile Pocahontas No. 3-bed
eye No. 3 mine, Raleigh County, W. Va.), (4) Bevier-bed and Quality
coals, and (5) McAlester-bed, Dow No. 10 mine, and Hartshorne-bed,
17 mine coals. In addition, carbonization tests were made both at
and 1,000° C. on 40:60, 50:50, and 60:40 blends of McAlester-bed,
rdi mine, and Hartshorne-bed, San Bois No. 14 mine coals; on a 60:40
d of this McAlester coal and Stigler bed, Garland mine coal; and on a
5:25 blend of Bernardi, San Bois No. 14, and Garland mine coals.

The Henryetta coal is high-volatile B; the Bevier and the two McAlester
s are high-volatile A; the Stigler bed and Hartshorne bed, San Bois No.
dine coals are medium-volatile; and the other three Hartshorne bed coals
low-volatile bituminous in rank. The chemical composition of the nine
s is normal for coals of their respective ranks. Henryetta, Bevier, and
two McAlester coals from Dow No. 10 and Bernardi mines contained 12.7,
, 10.9, and 9.6 percent oxygen, on the as-carbonized basis. The Henryetta
l also contained relatively high moisture and sulfur, namely, 6.8 and 2.1
cent, and Bevier coal has a sulfur content of 2.4 percent on the as-
bonized basis. Petrographic analyses showed that Henryetta, Bevier, and
lester (Dow No. 10 mine) were 100 percent bright coal and contained 3 to
ercent fusain; Hartshorne (No. 17 mine) contained 98 percent bright coal,
ercent semisplint, and 5 percent fusain. Mineral matter was well-dis-
buted uniformly in all coals except Bevier, which contained a 2-inch layer
high-ash coal at the top of the bed. Agglutinating values for the 15:1
io of silicon carbide to coal were: Henryetta, 4.5; McAlester, (1) Dow
10 mine, 5.4, and (2) Bernardi mine, 7.0; Hartshorne, (1) Great Western
e, 5.7, (2) No. 17 mine, 7.0, (3) Quality mine, 10.1, and (4) San Bois
14 mine, 9.8; Stigler, 9.4; and Bevier, 8.7. Bevier coal was highly
astic; it attained a maximum fluidity of 1,140 dial divisions per minute
404° C. in the Gieseler test, whereas the fluidity of the other three
gh-volatile coals was less than four dial divisions per minute. Yields
carbonization products from the high-volatile coals varied according to
eir composition and plastic properties. The two McAlester coals contained
gher fixed carbon and yielded more coke at 900° C. and more gas at all
rbonizing temperatures than were obtained from the highly fluid Bevier
al, which yielded more tar and light oil than the McAlester coals.

The high moisture content of Henryetta coal accounted for its high
eld of liquor. Blending with low- or medium-volatile coals increased the
eld of coke and decreased the yields of tar and light oil. Cokes from
e 100 percent charges of high-volatile coals were weaker than cokes ob-
ined from representative eastern gas coals. McAlester-bed, Dow No. 10
ne coal yielded the weakest coke of all, but the Bernardi mine coal from
e same bed gave much stronger coke. This difference in coking power of
ese two McAlester-bed coals reflects differences in their contents of
ygen, agglutinating values, and plastic properties. Blending Henryetta
d Bevier coals with low-volatile Hartshorne coal greatly increased the
rength of the coke, and the content of sulfur was reduced when Quality mine

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coal was used in the blend. Blends of Bevier with 20 and 30 percent Quality mine coal yielded stronger coke than blends containing the same proportions of Pocahontas No. 3 coal. McAlester coal from the Bernardi mine yielded strong coke when blended with 40 and 50 percent medium-volatile Hartshorne coal and with 40 percent Stigler coal. These medium-volatile coals yielded strong coke when carbonized alone, but they expanded too strongly to be used safely along in byproduct ovens.

Tests in movable-wall ovens by the Koppers Co. and by the Bureau of Mines indicated that a 50:50 blend of McAlester (Bernardi mine) and Hartshorne (San Bois No. 14 mine) can be carbonized without damage to oven walls through expansion. The 50:50 blend of McAlester (Bernardi mine) and Stigler coals was judged unsafe by similar tests, and a 50:25:25 blend of these McAlester and Hartshorne coals and Stigler coal was judged safe. The gases from all nine coals were relatively lean on the basis of the yield of 900° C. gases, expressed in British thermal units per pound of coal. The gases contained relatively large volumes of hydrogen sulfide. No relationship could be established between the forms of sulfur in the coal and the distribution of sulfur in the gas and coke. Bevier coal differed greatly from Henryetta and McAlester coals in respect to oxidizing properties. It withstood the effects of oxidation exceptionally well, whereas Henryetta and McAlester coals lost their coke-making power rapidly. Stigler coal oxidized slowly; its characteristic rate of oxidation in air at 100° C. was 0.255, which is almost as low as the rate of 0.236 for Pittsburgh-bed coal. Corresponding rates for Hartshorne (San Bois No. 14 mine), McAlester (Bernardi mine), and McAlester (Dow No. 19 mine) coals were 0.335, 0.405, and 0.523, respectively.

The results of an investigation of the composition and carbonizing properties of Pocahontas No. 3 coal from Kimball, McDowell County, W. Va., have been published.75/ Chemical analyses, agglutinating values, plastic characteristics, assays at high and low temperatures, expansion tests, and Bureau of Mines-American Gas Association carbonization tests at 500°, 600°, 700°, 800°, 900°, and 1,000° C. were made. Oxidized samples were carbonized at 800° C., and blends with high-volatile Pittsburgh-bed coals at 900° C. Pocahontas No. 3-bed coal ranks as a low-volatile bituminous coal. It contains 2.4 percent moisture, 16.6 percent volatile matter, 75.8 percent fixed carbon, 5.2 percent ash, and 0.7 percent sulfur on the as-carbonized basis. The ash softened at 2,400° F. The proportions of ash and sulfur are well below the limits specified for coals suitable for the production of metallurgical coke. The agglutinating value, at a silicon carbide-coal mixture of 15:1, was 10.9 and the maximum plasticity by the Gieseler plastometer was 2.7 dial divisions per minute at 481° C.

75/ Davis, J. D., Reynolds, D. A., Ode, W. H., and Holmes, C. R., Carbonizing Properties of Pocahontas No. 3-bed Coal from Kimball, McDowell County, W. Va., and the Effect of Blending this Coal with Pittsburgh-bed Coal: Bureau of Mines Tech. Paper 670, 1944, 35 pp.

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The yields of carbonization products in the 18-inch BM-AGA retort test at 900° C. were: Coke, 82.8 percent; gas, 10,500 cubic feet; tar, 3.5 gallons; light oil in gas, 1.32 gallons; and ammonium sulfate, 11.6 pounds, all expressed on the basis of a ton of coal. The coke was blocky, fine-grained, and stable; the gas had a specific gravity of 0.280 and a heating value of 504 B.t.u. per cubic foot (2,650 B.t.u. per pound of coal); and tar contained a relatively high percentage of residue on distilling to 350° C. and relatively low percentages of neutral oil and acids. Blending with 70 and 80 percent Pittsburgh-bed coal decreased the coke yield and increased the yield of by-products. Oxidation for 16.1 days virtually destroyed the coking property.

Previous investigations have indicated that the coke-making properties of predominantly splint coals are unlike those of bright coals of similar rank. A comparative study[76] was made of the carbonizing properties and petrographic composition of four medium-volatile bituminous coals, all from the Appalachian region. These coals were from the Lower Banner, Sewell, Lower Freeport, and Bakerstown beds. The Lower Banner bed contained 36 area-percent of bright coal, 53 of semisplint, and 11 of cannel; it contained 68 area-percent of attrital components as compared with 35 for Sewell and 31 for Lower Freeport and Bakerstown coals. The four coals are of nearly identical rank. In the order named, the percentages of fixed carbon in these coals, on the dry, mineral-matter-free basis, are 76.9, 77.5, 73.4, and 77.1, respectively. Judging from the chemical analysis alone, virtually the same carbonizing properties would be expected for the four coals. The marked differences found for the various carbonizing properties of Lower Banner coal as compared with the other three coals must be attributed to its peculiar type or petrographic composition.

Lower Banner coal, predominantly splint, differs from three medium-volatile Appalachian bright coals in that it yields weaker coke and contracts during carbonization. This difference is believed to be due to the dissimilar plastic properties of Lower Banner coal, which permit its volatile decompostion products to escape through the plastic layer easily and at relatively low pressures. Two explanations are indicated: (1) Splint and cannel constituents increase the fluidity of plastic coal and (2) splint and cannel constituents reduce the agglomeration or cohesive property below that necessary to retard the escape of volatile products. It seems apparent from these comparisons of medium-volatile bituminous coals of nearly identical rank that certain carbonizing properties are not predictable from chemical analyses and that petrographic composition may modify carbonizing properties more than has been generally recognized.

Coke from Blends of Coal and Its Coke Breeze

Pittsburgh-bed coal crushed to pass 1/4 inch was blended with 1, 3, and 5 percent of coke-oven breeze produced from this coal. The coke breeze was used in two sizes (1) fine coke crushed to pass 14-mesh and (2) coarse coke

76/ Reynolds, D. A., and Davis, J. D., Coal Carbonization - Carbonizing Properties of Medium-Volatile Coals of Different Types: Bureau of Mines Rept. of Investigations 3749, 1944, 8 pp.

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crushed to pass 4-mesh Tyler sieve. Table 10 shows the yields and physical properties of the cokes made from the coals and the several blends. Blending increased the yield of coke but did not significantly change the apparent specific gravity. Blending with 1 percent of coke breeze, either fine or coarse, affected but slightly the significant indexes defining physical properties of the coke. Additions of 3 percent of breeze raised the 1-1/2-inch shatter index from 61.0 to 70.3 when the breeze was fine; coarse breeze was somewhat less effective. The 1-inch tumbler index was increased somewhat with fine breeze but decreased sharply as the coarse breeze was raised to 5 percent. The 1/4-inch tumbler index was lowered by blending with both sizes of breeze; the effect was much more pronounced when coarse breeze was used in the larger proportions.

Coke from Blends of Coal and Low-Temperature Coke

A study was made of 90:10 and 80:20 blends of Pittsburgh-bed, Warden mine coal (coal 128) and "Disco" low-temperature coke made from the same coal to determine the effect of 10- and 20-percent additions of Disco on the yields and physical properties of the resulting cokes. The results are given in table 11, with those for cokes made from two 100-percent Warden coals and for two cokes produced from blends containing 80 percent of Warden coal and 20 percent, either of Pocahontas No. 3-, or of Pocahontas No. 4-bed coal. Disco coke of two different volatile-matter contents was used in two different sizes. Compared with Warden coal 128-1, the yields and apparent specific gravity of the resulting cokes were increased by both sizes of Disco. The addition of minus 1/16-inch Disco coke lowered the 1-1/2-inch shatter index in three out of four tests but raised the 1-inch and 1/4-inch tumbler indexes in all eight tests. The effects of the minus 1/8-inch Disco were more variable. In most tests Disco containing 17.8 percent of volatile matter was superior to that containing 19.9 percent. The Pocahontas No. 3 coal contained 17.4 and the Pocahontas No. 4 coal 16.0 percent volatile matter. Their blends with 80 percent of Warden coal gave larger yields of stronger cokes than cokes produced from blends containing 80 percent of Warden coal and 20 percent of Disco. It is evident that the volatile content of the low-volatile constituent of a coal blend is not the sole factor in determining the yield and quality of coke. Nor do the results obtained on blends of Warden coal and Disco coke mean that other high-volatile coking coals would react exactly the same as the Warden coal when used with the Disco coke in blends.

Laboratory Tests of Coking Properties of Western Coals

Coking coals are not abundant in the Western States, and considerable search is being conducted for suitable coals to make metallurgical coke. Southern Colorado and northern New Mexico have supplied most of the coke for steel making, but new plants at Fontana, Calif., and at Geneva, Utah, have placed greater emphasis on coals from Carbon County, Utah. These coals are high in oxygen and have relatively poor coking properties, but good performance in the blast furnaces can be obtained from cokes made from these coals, provided sized coke, ore, and limestone are charged. However, their coking power is affected rapidly by oxidation during storage.

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TABLE 10. - Yields and physical properties of cokes from Pittsburgh bed coal and blends of Pittsburgh coal with coke breeze

Test No.	Percent coke in blend	Yield of coke, percent	Apparent specific gravity of coke	Shatter test, cumulative percent upon-				Tumbler test, cumulative percent upon-			
				2-inch screen	1-1/2-in. screen	1-inch screen	1/4-inch screen	2-inch screen	1-1/2-in. screen	1-inch screen	1/4-inch screen
1	-	67.7	0.89	21.0	61.0	88.4	97.5	0.0	12.4	47.5	72.8
				(Fine coke 1/ in blends)							
2	1	68.2	.88	23.5	59.9	88.5	97.7	.7	17.0	52.1	72.3
3	3	67.7	.90	42.4	70.3	90.6	98.0	.0	22.7	52.8	71.3
4	5	69.5	.92	51.6	71.8	89.7	97.8	4.3	27.3	50.9	67.1
				(Coarse coke 2/ in blends)							
5	1	69.1	.88	42.6	67.9	86.8	97.3	.0	11.0	45.0	70.3
6	3	69.2	.89	41.1	69.6	84.6	96.8	.0	5.6	33.4	65.0
7	5	69.7	.89	50.2	69.1	83.8	96.3	.0	5.0	20.1	55.5

1/ Crushed to pass 14-mesh Tyler sieve.
2/ Crushed to pass 4-mesh Tyler sieve.

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TABLE 11. - Yields and physical properties of coke from blends of Pittsburgh-bed (Warden mine) coal and low-temperature Disco coke carbonized in 18-inch retorts at 900° C.

Test No.	Composition of charge	Disco coke: Volatile matter, percent	Disco coke: Size through, inch	Resulting coke: Yield percent	Resulting coke: Apparent specific gravity	Resulting coke: 1-1/2-in. shatter index	Resulting coke: 1-in. tumbler index	Resulting coke: 1/4-in. tumbler index
i28-A-1	90 percent Warden coal and 10 percent Disco	19.9	1/8	70.6	0.87	78.7	50.6	65.0
i28-A-2	90 percent Warden coal and 10 percent Disco	19.9	1/16	70.5	.88	68.7	51.6	68.2
i28-B-1	80 percent Warden coal and 20 percent Disco	19.9	1/8	72.0	.87	69.9	50.8	65.4
i28-B-2	80 percent Warden coal and 20 percent Disco	19.9	1/16	71.9	.91	69.0	51.1	68.8
i28-C-1	90 percent Warden coal and 10 percent Disco	17.8	1/8	70.8	.86	79.8	50.4	67.3
i28-C-2	90 percent Warden coal and 10 percent Disco	17.8	1/16	70.7	.89	68.6	53.3	71.1
i28-D-1	80 percent Warden caol and 20 percent Disco	17.8	1/8	71.0	.89	72.4	51.0	68.6
i28-D-2	80 percent Warden coal and 20 percent Disco	17.8	1/16	72.3	.89	77.6	54.3	68.6
i28-1	100 percent Warden coal			69.0	.86	76.9	50.8	67.3
28 1/	do			68.8	.88	68.0	55.2	71.5
56A	80 percent Warden coal and 20 percent Pocahontas No. 3-bed coal			84.0	.90	77.0	58.8	71.4
57A	80 percent Warden coal and 20 percent Pocahontas No. 4-bed coal			84.3	.91	79.5	60.3	71.8

1/ Original sample.

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The Golden (Colo.), Field Station has conducted systematic tests on coking properties of coals from western mines. Since November 1943 about 75 samples from Colorado, New Mexico, and Utah have been tested and the results summarized in table 12. The coking indexes given in the table have certain significance. For example, a coal having a combined coking index of less than 2.50 is a noncoking coal and will not fuse when carbonized. If the combined coking index is between 3.00 and 4.00, the coal has possible commercial coking properties, and, if the index is more than 4.00, the coal is suitable for coking in byproduct ovens. Likewise, the calculated coking index, obtained from the ultimate analysis of the coal,77/ is a guide in estimating coking or plastic properties of the coal. If the calculated coking index is less than 1.00 the coal is noncoking. If this index is between 1.00 and 1.10 it is a borderline coking coal and if above 1.20 the coal can be coked in byproduct ovens. The coking properties improve as the index increases in value.

Blending of different coals is being tried to improve coke structure. Low-volatile coking coal is in demand but because of the scarcity of coal of this rank in the Rocky Mountain region, Arkansas coal is now shipped to the west coast for blending purposes. It has been observed at the Kaiser coke plant, Fontana, Calif., that about 12 percent of low-volatile Arkansas coal with Carbon County (Utah) coal improves the structure of coke.

Byproduct Coke-Oven Tests of Washington Coals

The increased industrial activity on the West coast as a result of war conditions, curtailment of shipping, the Government program for utilization of water power from the Bonneville and Grand Coulee Dams, and the stimulus given by the national defense and war programs have all contributed to the expansion of the coking industry. An investigation was made to explore the possibilities of installing a Curran-Knowles byproduct coking plant in the Puget Sound area of Washington for utilizing Roslyn, McKay, and Wilkeson coals alone, in combination, or mixed with petroleum carbon or petroleum coke.78/ The principal problem, aside from that involving markets and other economic questions, concerned the suitability or amenability of the proposed method of coking in sole-heated ovens, the yields, and physical and chemical properties of coke made from representative coals under typical operating conditions.

77/ See footnote 59, p. 34.

78/ Yancey, H. F., Daniels, J., McMillan, E. R., and Geer, M. R., Byproduct Coke-Oven Tests of Washington Coals: Bureau of Mines Rept. of Investigations 3717, 1943, 46 pp.

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TABLE 12. - Agglutinating, swelling, and plastic properties of Colorado, Utah, and New Mexico coals

Colorado

Coal No.	Date sampled	Mine	Bed	County	B.S.S.T.[1]	Agglut. index	Plastometer			Coking indexes	
							Index	S.P., °C.	M.P., °C.	Comb.	Calc.
15	11/43	Tripple S	Fruita	Archuleta	5.14	4.6	3.68	375	433	4.46	1.10
16	11/43	Yellow Jacket	Yellow Jacket	do.	8.13	6.1	4.54	371	418	6.58	1.38
33	12/43	Carbon Junction	Unknown[2]	La Plata	8.25	4.4	2.66	381	442	5.42	1.26
26	11/43	Castle	-	do.	5.38	4.6	3.87	372	421	-	-
34	12/43	Coal King	Hesperus	do.	5.91	3.7	3.97	373	424	4.72	1.15
12	10/43	Dufur	do.	do.	5.03	3.6	3.16	381	434	4.19	1.11
13	10/43	Durkan	do.	do.	1.97	2.2	1.94	385	435	2.50	.99
17	11/43	Fort Lewis	-	do.	4.47	4.1	3.74	375	428	4.32	1.11
14	11/43	Haygulch	Hesperus	do.	1.81	.2	.67	395	446	-	-
27	11/43	King	-	do.	5.81	3.8	2.73	383	436	-	-
-	1/44	King Coal	Hesperus	do.							1.23
32	12/43	Morning Star	-	do.	6.44	4.7	4.86	363	408	-	-
24	11/43	O.K.	-	do.	1.63	.3	.77	382	437	-	-
-	1/44	Peacock	Hesperus	do.							1.23
28	11/43	Sunshine	-	do.	8.28	4.1	4.16	368	416	-	-
35	1/44	Supreme	Hesperus	do.	4.88	4.3	3.42	374	428	4.79	1.28
25	11/43	Victory	-	do.	6.58	4.3	4.05	370	417	5.50	1.33
10	10/43	Wright #1	Hesperus	do.	4.91	4.2	4.03	372	418	4.77	1.22
11	10/43	Wright #2	do.	do.	5.21	3.9	3.74	377	424	4.69	1.21
50	5/44	Anchor (Eureka)	Unknown	Las Animas	5.19	5.20	4.25	369	420	5.17	1.23
54	5/44	Baldy	No. 2	do.	2.62	2.50	1.24	385	440	3.52	1.39
58	5/44	Bear Canon 6	Bear Canon 6	do.	8.64	6.0	4.73	366	412	6.69	1.36
55	5/44	Berwind Canyon	Tabasco	do.	2.00	2.1	2.11	385	437	3.74	1.48
60	4/44	Boncarbo	Primero	do.	7.62	7.2	4.46	366	418	5.78	1.32
45	4/44	Frederick	Frederick	do.	8.75	9.4	5.30	366	396	8.30	1.56
57	5/44	Green Canon	Alta	do.	2.50	2.8	1.32	384	441	2.93	1.13
53	5/44	Grey Creek	No. 4	do.	7.62	4.3	3.29	376	430	6.05	1.50
59	5/44	Lovato No. 2	Primero	do.	8.50	7.7	4.35	368	415	6.88	1.32
44	4/44	Morley	Lower Seam	do.	5.50	4.6	3.93	371	423	5.53	1.42
51	5/44	[3]	Cameron	do.	1.75	.1	.44	390	426	-	-
56	5/44	Taylor	Tabasco	do.	5.12	4.3	3.42	375	433	4.85	1.28
49	5/44	Thor	-	do.	3.62	3.5	3.45	371	436	-	-

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TABLE 12. - Agglutinating, swelling, and plastic properties of Colorado, Utah, and New Mexico coals (Cont'd.)

Coal No.	Date sampled	Mine	Bed	County	B.S.S.T.[1/]	Agglut. index	Plastometer			Coking indexes	
							Index	S.P., °C.	M.P., °C.	Comb.	Calc.
Utah											
5	6/43	Columbia	Lower Sunnyside	Carbon	3.06	2.6	1.97	381	433	3.01	1.05
23	11/43	do.	do.	do.	4.82	3.3	2.43	382	436	3.85	1.10
4	6/43	Kaiser #2	do.	do.	4.44	2.9	3.41	372	438	3.86	1.08
21	11/43	do.	do.	do.	5.16	3.5	2.67	383	442	4.09	1.12
3	6/43	Sunnyside #1	do.	do.	4.72	2.8	4.00	370	421	4.25	1.17
20	11/43	do.	do.	do.	5.81	3.9	4.80	366	421	4.02	1.18
1	5/43	Castle Valley	Lower Hiawatha	Emery	2.00	.4	.57	383	418		
6	6/43	Geneva	Lower Sunnyside	do.	4.00	2.8	1.90	384	434	3.22	1.02
7	6/43	do.	do.	do.	4.44	3.0	2.76	382	432	3.74	1.09
8	8/43	do.	do.	do.	4.31	3.3	2.81	376	435	3.73	1.06
22	11/43	do.	do.	do.	4.25	3.2	1.74	383	435	3.36	1.03
2	5/43	Jim Peterson	do.	do.	4.60	3.1	3.15	374	425	3.75	1.02
New Mexico											
41	4/44	Brilliant #2	Raton	Colfax	7.81	4.8	4.12	371	414	6.20	1.42
-	5/44	Brilliant #2	do.	do.	-	-	-	-	-	-	1.37
46	4/44	Dawson No. 6	do.	do.	5.60	6.0	5.22	361	415	5.87	1.29
47	5/44	Denton	-	do.	3.69	3.9	3.59	373	436	-	-
43	4/44	Franks	Unknown	do.	4.16	4.6	3.40	377	442	4.36	1.15
52	5/44	Joe Sonehar	-	do.	4.50	3.7	2.05	384	440	-	-
40	4/44	Koehler 1 & 2	Raton	do.	4.80	5.1	3.84	370	425	4.72	1.13
-	5/44	do.	do.	do.	-	-	-	-	-	-	1.18
48	5/44	New Yankee #1	-	do.	4.56	4.8	2.91	378	437	-	-
42	4/44	Van Houten #4	Raton	do.	4.72	4.5	3.76	370	425	4.71	1.21
-	2/44	Viava	Black Diamond	McKinley	-	-	-	-	-	-	.89
-	3/44	Boardman	Grenko	do.	-	-	-	-	-	-	.88
-	3/44	Formerly Morris	Upper Seam	do.	-	-	-	-	-	-	.86

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TABLE 12. - Agglutinating, swelling, and plastic properties of Colorado, Utah, and New Mexico coals (Cont'd.)

New Mexico (Continued)

Coal No.	Date sampled	Mine	Bed	County	B.S.S.T.1/	Agglut. index	Plastometer			Coking indexes	
							Index	S.P., °C.	M.P., °C.	Comb.	Calc.
-	2/44	George	Aztee	McKinley	-	-	-	-	-	-	.86
-	2/44	Mentmore 1 & 2	No. 1	do.	-	-	-	-	-	-	.88
-	2/44	Mutual	Lower Measures	do.	-	-	-	-	-	-	.86
-	3/44	do.	No. 2	do.	-	-	-	-	-	-	.87
-	2/44	Navajo #5	No. 3-1/2 #5	do.	-	-	-	-	-	-	.88
-	3/44	Soper	-	do.	-	-	-	-	-	-	.90
-	2/44	South Western	Black Diamond	do.	-	-	-	-	-	-	.89
30	12/43	Amargo	Lower Seam	Rio Arriba	5.22	4.3	3.86	371	426	4.76	1.19
-	12/43	Caranta	Upper & Lower	do.							1.21
29	12/43	Rainbow	Upper Seam	do.	5.41	5.1	4.15	366	421	6.49	1.68
-	2/44	Black Diamond	Lower Bench	San Juan							.80
39	2/44	Morgan & Thomas	Local Seam	do.	3.90	3.5	.53	390	433	3.04	1.03
36	2/44	Smouse	Upper Bench	do.	1.00	.0	3.26	391	Slight	.23	.89
37	2/44	Stallings	Lower Bench	do.	1.00	.0	3.02	405	Slight	.29	.89
38	2/44	Toadlena	Unknown	do.	1.00	.0	2.00	400-415	Slight	.49	.86

1/ British standard swelling test, average of 8 buttons.
2/ Bed 40 feet thick or more.
3/ Southern Black Diamond Coal & Oil Co.

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The Curran-Knowles oven process is adapted to the carbonization of the coals mined at Roslyn and Wilkeson and will successfully coke blends of these coals with petroleum carbon. Box tests indicated that petroleum coke can be used as well as petroleum carbon. McKay coal, from Ravendale, does not appear at this time to be suitable for improving coke, but its value as a low-ash constituent should not be overlooked if future development of these coals warrant its use. All the coals and blends yielded commercial coke with relatively low sulfur, between 0.3 and 0.5 percent. The total yields, calculated on as-received basis, average 71.0 percent. The shatter and tumbler tests indicate generally that the coke breaks more readily than some of the cokes formerly available in local Northwest markets, but not to the extent that this property would be markedly disadvantageous. The conclusion was reached that these coals, or blends of generally similar combinations, will yield cokes suitable for domestic, smelter, general industrial, metallurgical, electrochemical, and electrometallurgical purposes. The phosphorus content might prohibit employing these coals for some highly specialized uses in the electrometallurgical field, especially for making ferro-alloys. Water-gas manufacture can be carried out with some of the strongest of these cokes, and some can be used for foundry and iron blast-furnace purposes if conventional operating practices are modified or if the present rigorous specifications for such cokes can be altered.

Tests of the Heliopore Coal-Carbonization Power-Plant Process

The Congress provided that the Bureau of Mines should erect and test a pilot plant embracing the principles of the Heliopore coal-carbonizing, power-plant process.79/ The plant was installed and put into operation at Golden, Colo. Preliminary tests showed that the Heliopore plant, as originally constructed, needed modification to enable the coal and char to flow through the retort so that fair tests could be conducted. In the main, the retort lacked adequate heat-transfer area. To remedy this condition, a coal drier was designed and installed on top of the retort. This unit dried and preheated the coal charge by means of the exhaust hot gas before the coal entered the retort proper. Further tests yielded data that should be of value in the further development of continuous retorts for coal carbonization. Hot gas at 1,629° F. supplied the retort with 411,000 B.t.u. per hour, of which 258,000 B.t.u. per hour or 62.8 percent was transferred to the retort and drier. The coal feed averaged 362 pounds per hour. The average effective coal-carbonization temperature attained was 1,331° F. The temperature differential between the hot gases and the char at the point where the hot gases entered the retort was 298° F. The average differential in temperature between the hot gas and the coal or char throughout the drier and retort was 316° F.

The byproducts from these tests, on the basis of percent by weight of coal as charged, were: Char, 52.3; tar, 4.4; liquor, 28.0; and gas, 15.3. The yield of gas, measured at 60° F., 30 inches of mercury pressure, and saturated with water vapor was 3.25 cubic feet per pound of coal as charged.

79/ Fieldner, A. C., Davis, J. D., Parry, V. F., Schmidt, L. D., Elder, J. L., Goodman, J. B., Landers, W. S., and Goodwin, E. W., Tests of the Heliopore Coal-Carbonization Power-Plant Process: Bureau of Mines Rept. of Investigations 3733, 1943, 36 pp.

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The gross heating value under these conditions was 532 B.t.u. per cubic foot and 1,729 B.t.u. per pound of coal as charged. The heating value of the char produced was 13,400 B.t.u. per pound as compared with 10,050 B.t.u. per pound for the entering coal. The tar yield (4.4 percent) was equivalent to 10.8 gallons per ton of coal and was characterized by the small pitch (residue upon distillation to 350° C.) content and high tar-acid and olefin content. The liquor from the purifying train yielded 12.2 pounds of ammonium sulfate per ton of coal carbonized.

Effect of Acids and Alkalies on Carbonization Products

A summary of published work on the effect of acids and alkalies upon the carbonization products of coal was issued.80/ In general, the beneficial action of the reagents is not great and is largely offset by deleterious effects on certain of the carbonization products. Many of the conclusions are based on small-scale tests; and because similar or closely related studies differ in certain important respects, it is difficult to predict what success these treatments might have in industry.

Influence of Resins on Coking Properties

A study81/ was made of the influence of resins in a Utah coal on its coking properties. The coal examined was from the Blind Canyon-bed, Deer Creek mine, Huntington Canyon, Utah. The coal was first crushed to pass a 16-mesh Tyler sieve. One portion was treated twice with a sodium chloride solution of 1.1 specific gravity plus 1 part per million of tannic acid on which the resinous material floated and the coal sank. The treated coal was washed with water to remove salt and then dried in a rotating drum at 100° C. in an atmosphere of nitrogen. After cooling in nitrogen, it was carbonized at 900° C. in the 13-inch BM-AGA retort in the same manner as another portion of the raw coal. Approximately 2.8 percent of resinous material was removed by the float-and-sink treatment. The volatile combustible matter of the resinous material was 91.4 percent and the part insoluble in benzene by Soxhlet extraction 17.2 percent. Comparison of analyses of the treated and untreated coals showed that moisture and volatile matter were reduced and fixed carbon increased by the treatment. The lower moisture content of the treated coal was reflected in a lower yield of liquor in the BM-AGA carbonization tests. To make the data comparable, enough water was added to a sample of the treated coal to equal the moisture content of the raw coal. Yields of carbonization products were obtained on the raw coal containing 5.5 percent moisture, the treated coal containing 4.0 percent moisture, and the treated coal containing 5.5 percent moisture. Removal of resins from Utah coal increased the yield of coke and decreased the yield of tar; the effect on the volume of gas was insignificant but the

80/ Brewer, R. E., Effect of Acids and Alkalies Upon Carbonization Products of Coal: Bureau of Mines Rept. of Investigations 3726, 1943, 20 pp.

81/ Davis, J. D., and Reynolds, D. A., Influence of Resins in a Utah Coal on Its Coking Properties: Fuel in Sci. and Practice, vol. 23, March-April 1944, pp. 37-40.

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yield by weight was lowered. The coke was slightly inferior to that produced from the raw coal. None of the three samples produced cokes strong enough for iron smelting, as judged by western United States standards, but the cokes should serve for smokeless domestic heating. All samples gave exceptionally high yields of gas and tar of good quality. The coal offers possibilities for gas making, provided disposal of the coke is not too difficult.

Plasticity of Coal

The plastic properties of 31 coals, 5 coal blends, and 2 layer samples of coal, whose ranks and sources are given in table 13, were determined during the fiscal year. The coals named in the table are arranged in decreasing order of rank, as expressed by dry, mineral-matter-free fixed carbon content. Most of the tests, made in duplicate by two different methods, were in connection with studies of (1) other properties of coal, such as carbonizing, expanding, oxidizing or storage, (2) explorations of new coal reserves, and (3) special points in the test procedure of the Gieseler-type plastometer for measuring the plastic characteristics of coal. The effect of storage on the plastic properties was determined on a number of coals that had been stored for known periods of time in closed containers filled with coal, except for the air remaining in the void spaces between the coal particles, of sizes as crushed for coking. The bright layer sample of Pocahontas No. 3-bed coal still showed appreciable plastic properties after 4 years' of storage, whereas the medium-volatile Stigler- and Rod Ash-bed coals showed pronounced reduction in plastic properties after only 4 months of storage. Tests of the plastic characteristics of various blends of Eagle-bed coal with other coals were made in connection with studies of the carbonizing properties of this coal and its blends. The Eagle-bed coal showed a very much higher fluidity than that of Powellton bed, No. 7 mine coal. These two coals are mined in Kanawha County, West Virginia, and are of almost identical rank. They might be expected to show the same plastic properties, when judged by rank alone. Numerous earlier tests made on samples from the Eagle bed in the Bureau of Mines and other laboratories have shown that this coal is one of the most fluid coals mined in America. A Powellton-bed coal from Coal Mountain mine, Wyoming County, West Virginia showed appreciably greater fluidity than the Powellton coal from No. 7 mine, but much lower than the Eagle coal. The high-volatile A bituminous Pittsburgh-bed coal from Morgantown, W. Va., although of comparable rank to the Eagle and the two Powellton coals, showed low fluidity. It may be concluded that the plastic properties of coals cannot be predicted exactly from rank alone, nor can the plastic characteristics of coal blends be accurately foretold by calculation from the constituent coals.

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TABLE 13. - Rank and source of coals tested

Low-volatile bituminous

Bright layer, Pocahontas No. 3 bed, Buckeye No. 3 mine, Wyoming County, W. Va.
Splint layer, Pocahontas No. 3 bed, Buckeye No. 3 mine, Wyoming County, W. Va.

Medium-volatile bituminous

Stigler bed, Garland mine, Oklahoma.
Composite of three tipple samples, Red Ash bed, Red Ash Smokeless mine, McDowell County, W. Va.
70:30 blend of Eagle bed, Carbon Fuel Company mine, Kanawha County, W. Va., and Pocahontas No. 3 bed, Buckeye No. 3 mine, Wyoming County, W. Va.

High-volatile A bituminous

Eagle bed, Carbon Fuel Company mine, Kanawha County, W. Va.
80:20 blend of Eagle bed and Pocahontas No. 3 bed.
50:50 blend of Eagle bed and Powellton bed, No. 7 mine, Kanawha County, W. Va.
Powellton bed, No. 7 mine, Kanawha County, W. Va.
Powellton bed, Coal Mountain mine, Wyoming County, W. Va.
60:40 blend of Eagle bed and Stigler bed, Garland mine, Oklahoma.
Pittsburgh bed, U. S. Army Ordnance, Morgantown, W. Va.
80:20 blend of Pittsburgh bed and Pocahontas No. 3 bed.
Mary Lee bed, core-drill hole No. 13-43, Walker County, Ala.
Mary Lee bed, Top Bench, core-drill hole No. 14-43, Walker County, Ala.
Mary Lee bed, Bottom Bench, core-drill hole No. 14-43, Walker County, Ala.
Mary Lee bed, Top bench, core-drill hole No. 15-43, Walker County, Ala.
Mary Lee bed, Bottom Bench, core-drill Hole No. 15-43, Walker County, Ala.
Frederick bed (washed), Pueblo, Colo.
Selected layer, Harrisburg No. 5 bed, Thurmond mine, Gallatin County, Ill.
Elkhorn No. 3 bed, Wheelwright mine, Floyd County, Ky.
No. 6 bed (unwashed), Jonesville Coal Company mine, Washington.
Roslyn No. 5 bed (unwashed), Northwestern Improvement Company No. 3 mine, Washington.
Roslyn No. t bed (washed), Northwestern Improvement Company No. 3 mine, Washington.
Willow Creek bed, main middle bed, core-drill No. 4-31, Kemmerer, Wyo.
Willow Creek bed, lower bed, core-drill No. 4-31, Kemmerer, Wyo.

High-volatile B bituminous

Column sample, Harrisburg No. 5 bed, Thurmond mine, Gallatin County, Ill.
Spring Valley bed, Lees mine, Lincoln County, Wyo.
No. 3 bed, Sweetwater No. 2 mine, Sweetwater County, Wyo.
No. 9 bed, Pacific mine, Muhlenberg County, Ky.
No. 9 bed, oxidized 7 days in air at 100° C., Pacific mine, Muhlenberg County, Ky.
No. 6 bed, Dawson Collieries mine, Hopkins County, Ky.
Lower Sunnyside bed, Columbia Steel Corporation mine, Utah.
Lower Sunnyside No. 1 bed, Sunnyside mine, Carbon County, Utah.
Lower Sunnyside bed, commercial shipment, Carbon County, Utah.

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TABLE 13. - Rank and source of coals tested (Cont'd.)

Subbituminous A

Plus 1-1/4" float on 1.35 sp. gr., Coalmont bed, Moore mine, Jackson County, Colo.

Subbituminous B

Monarch bed, Monarch mine, Sheridan County, Wyo.

Lignite

Velva mine, Ward County, N. Dak.

The plastic properties of the last 25 coals listed in table 13 were determined in connection with studies of their coking properties, as determined by the BM-AGA survey method. All of these coals, at present, are not used or are used only to a limited extent commercially for coking purposes. Studies of the plastic properties of the core-drill samples from different benches of the Mary Lee bed in Alabama and of the Willow Creek bed in Wyoming made possible correlations of the plastic properties of the different coals in the mineable benches. The Frederick-bed coal from Colorado, the selected layer from Harrisonburg No. 5 bed from Illinois, and the Elkhorn No. 3 bed from Kentucky showed plastic properties that indicate fair coking properties. The Frederick coal formed a spongy coke, which can be counteracted by proper blending. The selected layer of the Illinois coal contained only 4.3 percent ash, as compared with 20.8 percent ash in the column sample of this coal. The high ash can be reduced considerably by treatment, making available a new coking coal. The Elkhorn coal, while not as good as some other Elkhorn coals, with proper preparation should be a good source of coking coal. The three high-volatile A Washington coals and the high-volatile B coals showed rather rapid oxidation. For example, the two Roslyn-bed Washington coals, after several weeks of storage, showed a marked reduction in their plastic properties and No. 9-bed coal from Kentucky after 9 days has almost completely lost its fusion properties. The lower-ranking, high-volatile B bituminous showed poor fusion properties as measured by the plastometer tests. The subbituminous coals and the lignite did not fuse at the normal rate of heating of 3° C. per minute.

The Gieseler-type plastometer test method has undergone some minor changes in construction and operating technique since its initial development by the Bureau of Mines in 1939. The proposed method, as published[82/] in 1943 for information only, represented the consensus of experience of members of Subcommittee XV on Plasticity and Swelling of Coal, Committee D-5 on Coal

82/ American Society for Testing Materials, Proposed Method of Test for Plastic Properties of Coal by the Gieseler-Type Plastometer: Proc. Am. Soc. Test. Materials, vol. 43, 1943, pp. 301-305.

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and Coke, of the American Society for Testing Materials, who were then regularly using the Gieseler apparatus in different laboratories. Two main differences were noted at that time in the operating technique as practiced in two laboratories. These differences were (1) the manner of using the brake between observations of the dial movement, and (2) the use or non-use of a washer inserted in the retort above the compressed charge of coal. A series of tests on a number of bituminous coking coals of various ranks were made to study these points of difference. It was found that all readings for a coal having a fluidity of less than 150 dial divisions could be made without the use of the brake. This method of observation proved to be fully as reliable and much less tedious than the proposed technique in which the brake is alternately set and released before each reading. The use of the brake is unnecessary in testing coals of low fluidity and is not recommended. Tests on a large number of coals of various swelling powers were made with and without the washer inserted in the retort above the coal charge. It was found that the washer does not accomplish its claimed purpose in preventing swelling of the coal out of the retort and into the barrel of the plastometer. One coal even showed greater swelling when the washer was used. This condition may result from the fact that once a large amount of liquid and plastic material is pushed from the heated coal charge into the barrel above the level of the washer, it is then retarded from falling back into the retort because of its continual decomposition into semicoke which does not get back through the hole in the washer. It is recommended that the use of the washer be discontinued. The effect of the use of the washer and other points in operating technique have been discussed.83/

Swelling Properties of Coal During the Coking Process

Expansion tests in the sole-heated oven were made on three high-volatile bituminous coals included in the BM-AGA Survey of American Coals and of blends of these coals with low-volatile Pocahontas No. 3 coal. Table 14 shows the results of these tests and 17 tests made on different samples of Beckley-bed coal. Special interest is attached to the tests on Eagle-bed coal and blends of this coal with Powellton-bed coal because these two coals may be mined together through a single shaft. The sample of Eagle coal was obtained from a prospect hole extending from the Powellton bed, since this part of the Eagle bed is undeveloped. The results of the expansion tests indicate that all of these coals and blends would be safe to use in byproduct ovens. An additional check in the vertical slot oven on the ternary blend containing equal parts of Eagle and Powellton coals with 30 percent Pocahontas No. 3 coal charged at an approximate dry bulk density of 48.4 pounds per cubic foot showed a maximum wall pressure of 1.5 pounds per square inch. This result substantiates the sole-oven data in indicating that this blend is safe for byproduct oven use.

83/ Brewer, R. E., Discussion of "The Gieseler Method for Measurement of the Plastic Characteristics of Coal," by Glenn C. Soth and Charles C. Russell: Proc. Am. Soc. Test. Materials, vol. 43, 1943, pp. 1190-1191.

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TABLE 14. - Expansion in the sole-heated oven, calculated to a charge density of 55.5 pounds per cubic foot

Coal No.	Composition	Expansion, percent,
82	100 percent Eagle bed, West Virginia	-21.2
83	100 percent Powellton bed, West Virginia	- 9.0
82C	50 percent Eagle (82) + 50 percent Powellton (83)	-17.2
82A	80 percent Eagle + 20 percent Pocahontas No. 3 (75)	-11.8
82B	70 percent Eagle + 30 percent Pocahontas No. 3	- 5.9
82D	35 percent Eagle + 35 percent Powellton + 30 percent Pocahontas No. 3	- 3.6
86	100 percent Elkhorn No. 3 bed, Kentucky	- 1.0
86A	80 percent Elkhorn No. 3 (86) + 20 percent Pocahontas No. 3 (75)	+ 5.1
86B	70 percent Elkhorn No. 3 + 30 percent Pocahontas No. 3	+ 6.7
XP39	Beckley bed, West Virginia	+14.4
XP40	do.	+19.9
XP41	do.	+26.4
XP42	do.	+ 8.9
XP43	do.	+13.4
XP44	do.	+12.1
XP45	do.	+15.8
XP46[1/]	do.	+37.4
XP47	do.	+22.8
XP48	do.	+ 7.0
XP49	do.	+ 7.6
XP50[1/]	do.	+ 7.4
XP51	do.	+17.1
XP52	do.	+15.6
XP53	do.	+ 7.0
XP54	do.	+17.6
XP55	do.	+21.3

1/ Single tests.

A thorough study of the expanding properties of Beckley-bed coal from Wyoming County, W. Va., was made to determine its suitability as a substitute for Pocahontas No. 3-bed coal for blending with high-volatile Kentucky coal. There are no mines in the Beckley property intended for development, but samples were taken in the adjacent Glen Rogers, Glen White, Eccles, and Slab Fork mines. It is believed that results of tests of these samples give a good idea of what may be expected in the undeveloped property. Seventeen samples of Beckley coal and several samples of Pocahontas coal were tested under the same condition to compare the two coals. Expansion tests were made in the sole-heated and vertical-slot ovens. The more significant of the results from the sole-heated oven are given in table 14.

Elkhorn coal contracted but slightly on carbonization in the sole-heated oven at high bulk densities, and its blends with Pocahontas No. 3 coal expanded moderately. A blend containing 70 percent Elkhorn and 30 percent Beckley (Glen Rogers mine) developed 0.9 pound per square inch pressure in the vertical-slot oven and a similar blend of Pocahontas and

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Elkhorn coals developed 0.7 pound pressure. These blends could be used safely in byproduct ovens. Tests made in the sole-heated ovens on 100 percent charges of Beckley coal showed a wide range in expanding properties for the various samples from four mines. The Beckley bed is irregular in this district and some of the samples represent the full thickness, whereas others were from the top or bottom benches. These differences in the samples may account for differences in the expanding properties.

The small-scale, vertical-slot oven which was designed and built last year was tested under different operating conditions. This oven is similar in principle to the large vertical oven in that two walls, one of which is movable, are heated electrically and that carbonization expansion pressures may be measured at constant volume. The carbonizing chamber is 12 inches wide by 13 inches high, and the charge weighing about 17 pounds is 5 inches thick. The oven is shown open in figure 7 and closed for testing in figure 8. Its construction and operating characteristics are satisfactory; the heating elements are unaffected by the carbonization products, and transmission of expansion pressure to the movable wall is virtually frictionless. Analysis of the results of tests completed during the past year indicates that freedom of movement of the top boundary of the charge greatly affects the expansion pressure on the walls. The tests were made with the top of the charge under pressures to simulate the lower sections of byproduct ovens and also with top voids as obtained in the large-scale vertical slot oven. The latter method promises to be the better but results obtained to date are erratic and duplicate determinations frequently show poor checks. There seems to be an inherent tendency in small-scale tests toward exaggeration of expansion pressures, so that empirical modifications are necessary to obtain results comparable to large-scale results. It is hoped that further experimentation with this oven will yield more satisfactory results and that it can be used for many of the tests now made in larger test ovens which require more time and personnel. Temperature measurements in a charge carbonized in the small oven at rates about the same as those obtained in byproduct ovens indicated that the two individual plastic layers average about 0.2 inch in thickness near the walls, they then widen as they approached the center until at the time of coalescence the double layer is about 1.4 inches thick. Lowering the carbonizing temperature by 100° C. increased slightly the thickness of the plastic layer.

Problems of Metallurgical Coke for Western Furnaces

Metallurgical coke and the byproducts of the carbonization of coal continue in strong demand. In cooperation with the Government-Industry Advisory Committee on Improving Coke Production, the Bureau of Mines has conducted studies on control of impurities in mine-run, metallurgical coal, selective mining of metallurgical-grade coal, effect of control of bulk density of the coke-oven charge on the optimum physical properties of the coke, and other problems, the solution of which, should aid in maintaining maximum rate of production of good-quality coke. A general statement of the problems involved has been published.[84]

84/ Fieldner, A. C., Problems of Metallurgical Coke for Western Furnaces Being Solved-Byproducts in Demand: Min. and Met., vol. 25, 1944, pp. 101-102.

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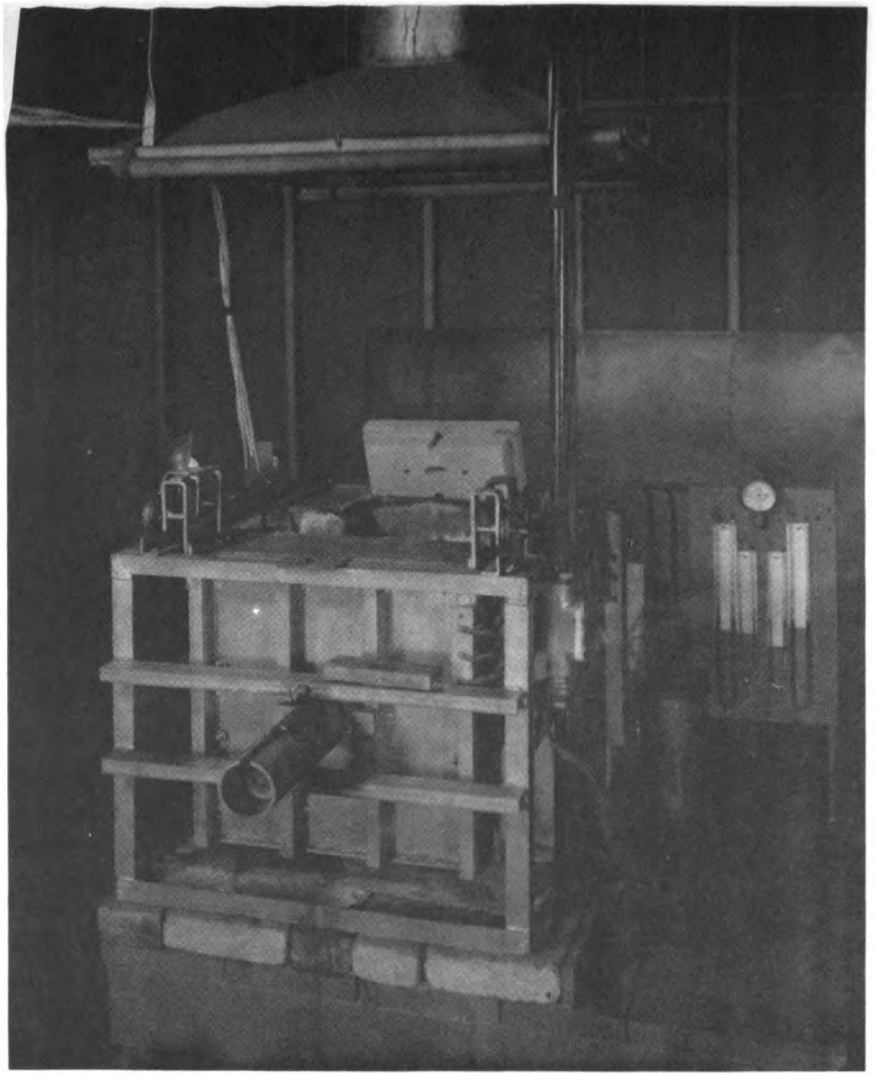

FIGURE 7.- Expansion oven, open.

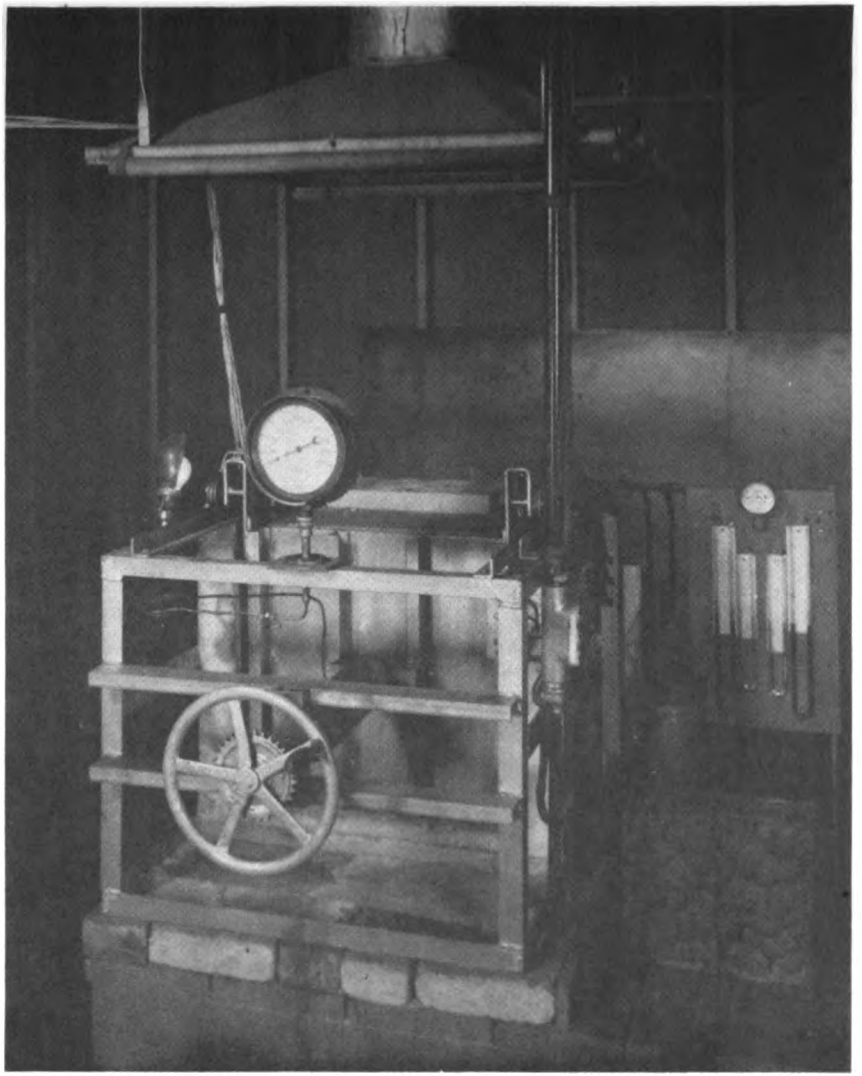

FIGURE 8.- Expansion oven, closed.

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It has been indicated that the production of pig iron could be increased appreciably if present blast furnaces were supplied with a more uniform coke. One cause of nonuniformity of the coke produced by ordinary American plant practice is the prevailing lack of precise control of the bulk density of the coal charge in the byproduct oven. This problem is an individual one for each plant and local conditions must be considered in determining its solution. Information on this problem has been collected and published by the Bureau[85] to aid the coke-plant operator in his endeavors to obtain more uniform coke. Since air-dried coal has the highest bulk density, care must be taken in using dry coal to avoid dangerous expansion, pushing difficulties, and nonuniform oven operation. This condition can be alleviated by adding water to the dry coal. The effect of moisture is very pronounced, especially in the lower ranges. Where lower bulk density is desired and the initial moisture is not too high, addition of water may result in more uniform bulk density.

The use of oil for the control of bulk density seems to be desirable, since it decreases the bulk density of dry coal and increases that of wet coal. Bulk-density control by the use of oil may increase production under certain conditions, but it is necessary to observe caution in a plant that employs expanding coals to an extent that the expansion pressure of the coal is near the permissible maximum. In addition, the use of oil aids in diminishing dust, causes the coal to flow more freely from the larry car, and lessens difficulties due to freezing in cold weather. In general, finer crushing gives lower bulk density. More uniform coke can be obtained if exactly the same weight of coal is charged to each oven each time.

Beehive-Coke Production

Contributing 11 percent of the total requirements of this country, beehive coke has proved a most important source of blast-furnace fuel for our wartime steel program. The beehive oven, long ago abandoned as obsolete, has in some ways proved to be a savior of the necessary expanding steel industry.[86] To assist beehive-oven operators in their efforts to produce fuel of good quality, the Bureau recruited a crew of field engineers and equipped a special mobile laboratory with instruments for measuring oven temperatures and oven-draft conditions, sampling and analyzing exit gases, and making float-and-sink tests for refuse in coal. Aid was also rendered operators in procuring equipment and coal.

The technical services made available to the industry through the trained technicians and the mobile laboratory included the development of rapid field tests which showed that satisfactory coal from the Pittsburgh

85/ Seymour, W., and Schmidt, L. D., Control of Bulk Density of the Coal Charge in Byproduct Coke Ovens: Bureau of Mines Rept. of Investigations 3743, 1943, 13 pp.

86/ Kelley, J. A., Beehive Coke Industry Revived: Min. Cong. Jour., vol. 29, 1943, pp. 22-25.

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bed contained less than 4.2 percent refuse (sinks in 1.6 specific gravity).87/ Specially developed techniques for controlling combustion in beehive-coke ovens by analysis of exit gases showed that properly operated ovens operate with a deficiency, rather than an excess of air. Measurements with optical pyrometers and thermocouples indicated that constant oven temperatures of 2,200° F. produced good coke. When the coking process nears completion, these tests show that there is a well-marked trend toward an excess of air, which results in combustion of the coke and thus decreases the coke yield, unless special precautions are taken. The need of the beehive-coke industry for aid in meeting wartime demands is illustrated by the following data:

Range in properties of beehive coke received at one blast-furnace plant

	Percent
Sulfur	0.65 to 2.50
Ash	11.00 to 22.00
1/4-inch tumbler	53 to 64

Beehive ovens in many ways provide ideal standby capacity for coke production. (1) They are simple to operate, requiring very little skill, except that developed by experience; (2) they are low in first cost, approximately $1,000 to $1,500 with an annual capacity of 700 tons compared with a rectangular oven of the modern type, $2,000 to $3,500, with an annual capacity of 1,000 tons of coke; (3) unless deliberately destroyed to avoid taxation, beehive ovens deteriorate very slowly when not in use; and (4) beehive coke manufactured from good coal is as good as any other coke made.

Figures 9 and 10 show beehive ovens before and after rehabilitation. Figure 11 shows a coke-drawing machine improvised by one operator to help meet wartime demands.

Effect on Compression of Coal Charge on Coke Properties

Practices with Saar coals in Germany and to some extent on a small-scale in England have been to compress the charges before placing them in the coke ovens. By this means a higher-density charge is obtained; and, for the Saar coals, coke of better physical properties is said to be produced. The effect of compressing charges (increased charge density) of two weakly coking American coals - the Willow Creek bed coal from Gomer mine, Lincoln County, Wyo., and the Lower Sunnyside bed coal from Columbia mine, Carbon County, Utah - on the yield and physical properties of their cokes is shown in table 15. The table makes it clear that compression of the charges of these two coals makes no significant difference in the yields but does increase the apparent specific gravity. The shatter and tumbler data show that compression weakens the cokes.

87/ Scott, G. S., Kelley, J. A., Fish, E. L., and Schmidt, L. D., Modern Beehive Coke-Oven Practice. I. Preliminary Report: Bureau of Mines Rept. of Investigations 3738, 1943, 14 pp.

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FIGURE 9.- Beehive-coke ovens before rehabilitation.

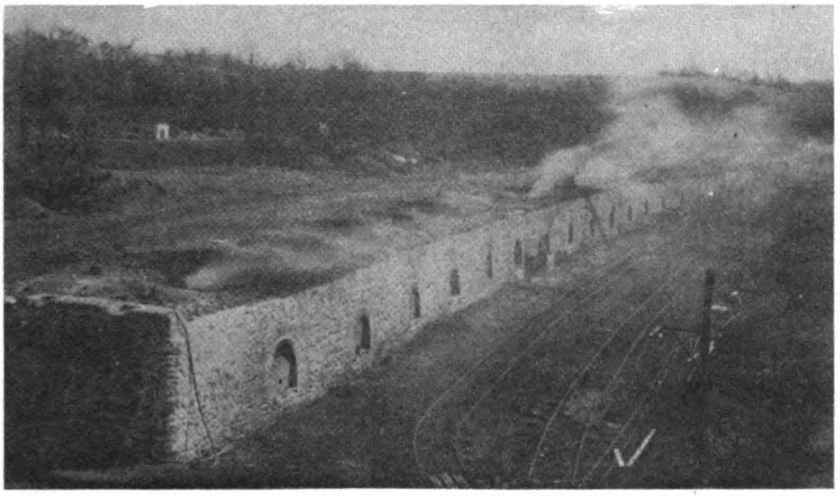

FIGURE 10.- Beehive-coke ovens after rehabilitation.

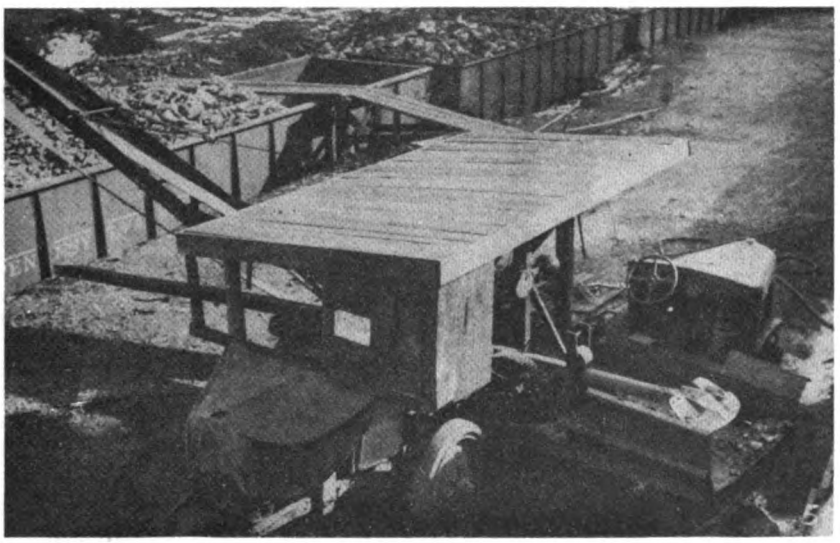

FIGURE 11.- Improvised coke-drawing machine.

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TABLE 15. - Yield and physical properties of cokes from Willow Creek (135) and Lower Sunnyside (e19) coals carbonized at 900° C.

Coal No.	Charge density, lb. per cu. ft.	Yield of coke, percent	Apparent specific gravity	Shatter test, cumulative percent upon-				Tumbler test, cumulative percent upon-			
				1-1/2-in. screen	1-inch screen	3/4-inch screen	1/2-inch screen	1-1/2-in. screen	1-inch screen	3/4-inch screen	1/2-inch screen
135	49.2	64.2	0.80	48	76	83	89	10	41	52	62
135	55.1	64.8	.85	30	65	77	87	3	32	47	61
135	58.9	64.8	.88	25	63	76	86	2	29	47	62
e19	50.9	63.0	.78	29	67	80	92	6	44	62	76
e19	52.6	62.8	.79	23	63	79	92	5	42	62	77
e19	56.1	62.8	.81	19	63	79	91	3	41	62	77
e19	59.3	62.9	.84	18	59	77	91	3	32	56	76

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Producer-Gas Investigations

Despite the inconvenience and decreased power availability of producer gas, the fuel economy of this country may yet provide an impetus for its use as fuel in fleets of trucks or buses.[88] Recent tests based on the operation of an updraft-type producer, fired with charcoal and installed on a 2 1/2-ton truck loaded to rated capacity, indicated a fuel consumption of 0.57 pound per gross ton-mile, which, though high, would still result in an appreciable saving in cost of fuel, as compared with gasoline. Equipment for determining the suitability of typical American solid fuels for use in portable gas producers on automotive vehicles as a substitute for gasoline is being installed at the Central Experiment Station in Pittsburgh, Pa.

Liquefaction

Bureau of Mines Research

Bureau of Mines interest in the production of liquid fuels from coal and lignite began in 1924 when particular attention was given to low-temperature carbonization and liquefaction of coal. The Bergius commercial-scale pilot plant for the hydrogenation of coal at Mannheim, Germany, and a number of low-temperature carbonization plants in England, France, and Germany were studied. Further reports on the development of petroleum substitutes from coal stimulated activity in the United States in obtaining fundamental information relative to the effect of temperature, pressure, and nature of catalyst and to the quantity and composition of the products obtained. The Bureau undertook laboratory experiments of the Fisher-Tropsch catalytic method for making liquid hydrocarbons from water gas. Although interest waned for a time, experimental work on the liquefaction of coal was resumed in 1936 when it became evident that a forward-looking policy from the national point of view should include preparation for the time when gradual exhaustion of petroleum resources would require supplementing with gasoline and Diesel oil produced from coal the growing demand for motor fuel. Reviews of Bureau of Mines research have been presented.[89] A small, continuously operating unit capable of hydrogenating 100 pounds of coal in 24 hours was installed at the Central Experiment Station of the Bureau of Mines at Pittsburgh, Pa. The Bureau is now undertaking the construction and operation of a pilot plant in which the converter units are nearer commercial size, so that data may be obtained for designing commercial

88/ Schroeder, W. C., Fuels and Fuel Research in Great Britain: Mech. Eng., vol. 65, December 1943, pp. 881-884, 892; discussion by W. T. Reid, Mech. Eng., vol. 66, May 1944, pp. 332-333

89/ Fieldner, A. C., Storch, H. H., and Hirst, L. L., Bureau of Mines Research on the Hydrogenation and Liquefaction of Coal and Lignite: Bureau of Mines Tech. Paper 666, 1944, 69 pp.; Am. Inst. Min. and Met. Eng. Tech. Pub. 1750, Class F. Coal Division, No. 156, 1944, 19 pp.; Trans. Am. Inst. Min. and Met. Eng., Coal Div., vol. 157, 1944, pp. pp. 341-362.

Fieldner, A. C., and Schroeder, W. C., Oil and Gasoline from Oil Shale and Coal: Fuel in Sci. and Practice, vol. 23, 1944, pp. 34-36.

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plants.90/ Investigations have demonstrated that the major part of the American reserves of coals is suitable for liquefaction. Coals low in ash and nearly free of fusain and opaque attritus can be almost completely liquefied. The yields, physical characteristics, and chemical composition of the resulting oils are influenced principally by operating conditions that vary with different coals. These operating conditions may be modified to produce either fuel oil or fuel oil, Diesel oil, and gasoline. The yield of tar acids is sufficiently large to be important commercially in the plastics industry. The yields of benzene, toluene, and xylene are of value for explosive manufacture and solvents. The high content of aromatic compounds in the neutral oil makes it a desirable blending base for high-octane aviation gasoline. The degree of liquefaction is roughly inversely proportional to its opacity. The yield of unliquefiable organic matter can be estimated approximately from the carbon content and petrographic composition of coals.

Mechanism of Coal-Hydrogenation Processes

The reactions in which hydrogen is "transferred" from one organic molecule to another during the hydrogenation of coal to produce liquid fuels have been studied and reported in a series of four publications, the latest of which appeared during the period covered by this report.91/ 92/ 93/ 94/

90/ Synthetic Liquid Fuels: Hearings before a Subcommittee on Public Lands and Surveys, U. S. Senate, 78th Congress, 1st Session on May 12, 1943, Washington, D. C., August 3 and 4, 1943, pp. 1-178; Pittsburgh, Pa., August 6, 1943, pp. 179-273; Salt Lake City, Utah, August 9, 1943, pp. 275-407; Sheridan, Wyo., August 11, 1943, pp. 409-469, U. S. Government Printing Office, Washington, D. C., 1943, 469 pp.
Public Law 290, 78th Congress, Chapter 172 - 2d Session, An act authorizing the construction and operation of demonstration plants to produce synthetic liquid fuels from coal, oil shales, agricultural and forestry products, and other substances, in order to aid the prosecution of the war, to conserve and increase the oil resources of the Nation, and for other purposes, April 5, 1944.

91/ Storch, H. H., Hirst, L. L., Fisher, C. H., and Sprunk, G. C., Hydrogenation and Liquefaction of Coal, Part I. - Review of Literature, Description of Experimental Plant, and Liquid-Phase Assays of Some Typical Bituminous, Subbituminous, and Lignitic Coals: Bureau of Mines Tech. Paper 622, 1941, 110 pp.

92/ Fisher, C. H., Sprunk, G. C., Eisner, A., O'Donnell, H. J., Clarke, L., and Storch, H. H., Hydrogenation and Liquefaction of Coal, Part 2. - Effect of Petrographic Composition and Rank of Coal: Bureau of Mines Tech. Paper 642, 1942, 162 pp.

93/ Hirst, L. L., Eisner, A., Field, J. H., Cooper, H. M., Abernethy, R. F., and Storch, H. H., Hydrogenation and Liquefaction of Coal, Part III. - Characterization of Assay Oils: Bureau of Mines Tech. Paper 646, 1942, 27 pp.

94/ Storch, H. H., Fisher, C. H., Hawk, C. O., and Eisner, A., Hydrogenation and Liquefaction of Coal, Part IV. - Effect of Temperature, Catalyst, and Rank of Coal on Rates of Coal-Hydrogenation Reactions: Bureau of Mines Tech. Paper 654, 1943, 50 pp.

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Experiments were made in small autoclaves on the effect of temperature, catalyst, and rank of coal on the rates of primary liquefaction, and of related processes, including the absorption of hydrogen and elimination of oxygen. The results show that the rate-determining step for the absorption of hydrogen varies with temperature. Between 300° and 370° C., diffusion of hydrogen through a liquid film on the surface of the coal and catalyst is the slowest step; above 370° C. the rate-determining step is a chemical reaction between a hydroaromatic and the oxygen and unsaturated groups in the primary decomposition of the coal. The chief function of the catalyst and of hydrogen at high pressure is to increase the rate of regeneration of hydrogen carriers which are hydromatic compounds, such as tetrahydronaphthalene. The reactions of the hydrogen carrier with oxygen groups and double bonds in the primary decomposition products of the coal appear to be largely noncatalytic. The accelerating effects of the catalyst on the rates of oxygen elimination and on that of liquefaction are similar, and both processes probably are intimately associated in one reaction or group of reactions.

No direct or simple relationship was found between the hydrogen-consumption rate and the rates of oxygen removal and of coal liquefaction. The presence of a reservoir of reactive hydroaromatic compounds that will transfer hydrogen to the products of the thermal decomposition of the coal substance seems to be largely responsible for this apparent lack of direct dependence of the liquefaction and oxygen removal rates on the rate of hydrogen consumption. For maintenance of this reservoir of reactive hydroaromatics, active catalysts and high pressures of hydrogen are essential.

To ascertain the nature of these hydrogen-transfer reactions a study was made of the mixture of anthracene plus tetrahydronaphthalene in the presence of an active hydrogenation catalyst.95/ A 30-percent yield of 1, 2, 3, 4-tetrahydroanthracene can be obtained by heating anthracene and tetralin at one atmosphere pressure in the presence of a palladium catalyst. When these two compounds are heated together in a sealed tube in the presence of this catalyst, the reaction resembles a catalytic hydrogenation of anthracene, and a 61-percent yield of 1, 2, 3, 4-tetrahydroanthracene is obtained, along with small amount of 9, 10-dihydroanthracene and 1, 2, 3, 4, 5, 6, 7, 8-octahydroanthracene. Other hydrogen carriers, such as 2-cyclohexenone, also bring about this type of hydrogenation of anthracene. The dehydrogenation of 9, 10-dihydroanthracene in the liquid phase results in the expulsion of less than the theoretical quantity of hydrogen and the formation of some 1, 2, 3, 4-tetrahydroanthracene. To determine those constituents of the recycle oil that are most active in primary liquefaction of coal and to devise methods for increasing the concentration of these constituents in the vehicle used to carry the coal, the effect of typical coal-hydrogenation catalysts on the rate of transfer of hydrogen from tetrahydronaphthalene to anthracene is being studied.

95/ Orchin, M., Hydrogenation of Anthracene by Tetralin: Jour. Am. Chem. Soc. vol. 66, 1944, pp. 535-538.

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Catalysts for Primary Liquefaction of Coal by Hydrogenation

Despite considerable work on testing catalysts for primary liquefaction of coal by hydrogenation, the high activity of the combination of tin and iodine has not been duplicated by any other catalyst or group of catalysts. The activity of tin may be due, in part, to its versatility in distributing itself throughout the solid, liquid, and gas phases of the hydrogenation system. It therefore alloys with the steel of the pressure vessel; it is found absorbed on the particles of fusain and durain and dissolved in the heavy oil; and there is some evidence that it enters the gas phase as volatile tin compounds.

A freshly machined stainless steel (18Cr-8Ni) surface enhances the activity of tin, but it is fouled after a short time by the adsorption of organic polymers of high molecular weight. In the Bureau of Mines continuously operating experimental plant a 3-inch I.D. by 96-inch-high converter was packed with stainless steel turnings. This packing increased the capacity of the plant by 50 to 100 percent for about 10 days, after which the enhanced activity due to the packing decreased for several days until the maximum throughput was about the same as with an unpacked converter. On the other hand, pumping hydrogen at 3,500 pounds per square inch and coal-oil paste plus 0.1 percent of the weight of coal of tin sulfide or tin hydroxide, through an unpacked converter, may be continued for months without any observable change in yield. It is probable, therefore, that alloying the tin with the steel of the converter wall does not contribute to the catalysis under conditions of long runs in which the steel walls are covered with a shellaclike layer of organic material of high molecular weight.

The catalysis by tin or tin alloys is not clearly understood. British investigations indicate no deterioration in the catalytic activity of acid-treated, tin-iron alloys when used for 13 consecutive small-autoclave tests, each of about 0.5 hour duration. The Bureau of Mines laboratory noted rapid deterioration of the enhanced activity of small amounts of tin in the presence of a large, alloy-steel surface after 10 days of continuous operation. Tin hydride is formed by the action of dilute solutions of organic acids on metallic tin in the presence of iron, the action being accelerated by the presence of minute amounts of halogens, such as iodine. The combination of tin and iodine is more active than either component alone. A possible mechanism that can explain most of the observed phenomena is that tin hydride reacts with cyclic olefins to form $R{=}SnH_2$, which decomposes to give RH_2 + Sn. The reaction is probably facilitated by prior saturation of of the olefin bond with iodine of hydrogen iodide: $RI_2 + SnH_4 \rightarrow (RH)HSnI_2 + H_2 \rightarrow RH_2 + Sn + 2HI$.

Synthesis of Liquid Fuels by Hydrogenation of Carbon Monoxide - Catalysts and Reaction Mechanism

The main components of catalysts (namely, iron, cobalt, nickel, and ruthenium) that are active in the synthesis of normally liquid hydrocarbons from hydrogen and carbon monoxide form relatively unstable carbides of nonionic crystal structures upon exposure to carbon monoxide in the temperature range of the synthesis. A critical review of literature on the

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preparation and properties of metal carbides has been published.[27] In the formation of carbides from finely divided metals and carbon monoxide three principal reactions can be distingusihed: (1) A rapid reaction proceeding on the surface before it has been converted with carbide and reaction products, (2) a slow reaction that may take weeks for completion, and (3) the formation of carbon, in addition to the carbide, if the temperature is above a characteristic value for each metal. The carbon formation continues until the iron is diluted to 1 percent of the total iron-carbon mass. All of the carbides of Fischer-Tropsch catalysts are more unstable than the true refractory carbides, such as calcium carbides. For all known Fischer-Tropsch catalysts the ratio of carbon-atom radius to metal-atom radius to metal-atom radius is equal to or greater than 0.58. The carbides of metals used as Fischer-Tropsch catalysts are more or less distorted interstitial compounds, with the carbon inserted into the interstices of the distorted metal lattice. It is almost inconceivable that carbide formation in the body of the catalyst will not profoundly modify the properties of the catalyst. The metal-to-metal distances will change. The electrical and magnetic properties will not remain the same. Hydrogen dissolved in the lattice probably will not behave the same, partly because many of the interstices in the metallic lattice are filled. The adsorption of the reagents and desorption of the products probably are modified by the carbides. Carbon formation, by carrying away active centers and producing irreducible residues on the catalyst; would tend to poison it. Whether this is really important in the Fischer-Tropsch synthesis is difficult to say at present.

The reaction between carbon monoxide and cobalt or iron or their oxides to form carbides is much too slow to account for the rate of the synthesis of hydrocarbons by reduction of the carbides with hydrogen when a mixture of hydrogen and carbon monoxide is used. It is known that the presence of hydrogen with carbon monoxide markedly accelerates the formation of carbon, which appears to proceed by way of the metal carbide. The following reaction is believed to be the main source of carbide: $2Co + CO + H_2 \longrightarrow Co_2C + H_2O$. This mechanism is difficult to apply to iron catalysts, however, where the main oxygenated product is carbon dioxide rather than water, as on cobalt catalysts. Since cobalt is a much more active catalyst than iron for the water-gas reaction and because the most active iron catalysts catalyze this reaction to only a slight degree at temperatures below 300° C., it appears probably that water and carbon dioxide are primary products on cobalt and iron catalysts, respectively. Although metal carbides are formed on both cobalt and iron, there is evidence that the mechanis of the synthesis on cobalt catalysts differs from that on iron catalysts. The ratio of the partial pressures of methane to ethane plus ethylene in the off-gases from the synthesis is markedly different for different catalysts, as shown in table 17. The ratio for cobalt is almost 20 times larger than that for iron-copper. This fact should be correlated with the previous discovery that on cobalt catalysts, ethylene mixed with synthesis gas participates in the synthesis to form normally liquid hydrocarbons, whereas on an iron-copper catalyst the added ethylene appears

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[27] Hofer, L. J. E., The Preparation and Properties of Metal Carbides with Critical Comment as to Their Significance in the Fischer-Tropsch Synthesis: Bureau of Mines Rept. of Investigations 3770, 1944, 39 pp.

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largely as ethane. An investigation has been made on the correlation of the physical properties, particularly X-ray diffraction pattern and ferromagnetism, of iron catalysts with their mode of preparation and activity.

Effect of Pressure and Dilution of Synthesis Gas with Nitrogen

Under a total pressure of about 1 atmosphere, dilution of synthesis gas with nitrogen decreases the yield of liquid hydrocarbons per unit volume of gas but does not decrease the precentage of conversion. In fact, such dilution results in a conversion somewhat greater than would be calculated on the basis of a first order reaction. This is shown in table 18 which contains results of recent work in the Bureau of Mines. As the reaction is approximately first order in the absence of diluents and the reaction rate in the presence of nitrogen is somewhat greater than corresponds to the partial pressure of the synthesis gas, it appears probable that the slow step in the reaction is the desorption of the products.

TABLE 17. - Bureau of Mines analyses of residual gas from Fischer-Tropsch Synthesis after one pass through catalysts

Catalyst	Co-ThO_2-kieselguhr	Fe	Fe-Cu
	Percent by volume		
Methane	45.7	38.3	14.8
Ethane	3.6	4.3	24.8
Ethylene	1.1	4.4	7.3
Propane	3.6	4.1	9.7
Propylene	5.4	6.6	16.4
Butanes	.4		1.2
Butenes	.8	.9	3.0
Carbon monoxide	32.2	37.5	4.7
Hydrogen[a/]	1.1	1.0	3.3
Carbon dioxide[a/]	.3	.4	.3
Nitrogen[a/]	5.8	2.5	15.0
Ratio C_1/C_2	9.8	4.4	.5

a/ Most of the carbon dioxide was removed by absorption in caustic before condensing the gas, and most of the hydrogen and nitrogen were separated by the condensation.

TABLE 18. - Bureau of Mines Results on Diluent effect of nitrogen using a cobalt catalyst

Nitrogen, percent	Yields in grams of oil per cubic meter	
	Observed	Calculated
1.0	101	-
16.3	88	84.5
28.8	90	72.3

An analysis of published data shows that the reaction rate is directly proportional to the partial pressure of the synthesis gas and inversely proportional to that of the products. The retardation of the rate by the

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products is sufficiently large so that only little advantage is obtained, so far as space-time-yield is concerned, by increasing the operating pressure to 5 to 20 atmospheres.

Research on Water-Gas Production

In an analysis of data in the literature on the reaction between steam and carbon98/ a mechanism of the reaction was proposed in which the rate of gasification increases with increasing steam pressure up to a critical pressure beyond which the rate does not change with pressure. The relationship is apparently determined by an adsorption isotherm with a saturation pressure. All of the available data had been obtained in systems at constant pressure in which the partial pressure of steam was varied by the change in the fraction of steam decomposed by altering the velocity of the steam passing through the bed of carbon particles. It was found that with increase in the partial pressure of the steam the rate of gasification approached a constant value. In these experiments, however, the gaseous atmosphere surrounding the carbon is not pure steam but a mixture of steam and the reaction products, hydrogen, carbon monoxide, and carbon dioxide, any of which may be adsorbed on the carbon surface. A more rigorous test of the proposed mechanism can be obtained by changing the total pressure of the system and maintaining a steam velocity high enough to obtain an atmosphere consisting almost entirely of steam. The partial pressure of the steam is then virtually equal to the total pressure.

As this reaction is typical of other gas-solid reactions such as carbon dioxide-carbon, it was considered desirable to undertake experiments at various total pressures and high-space velocities of steam. This work is also of importance in comparing carbons for reactivity in water-gas generation because the saturation pressure may vary with different types of carbon, and it should furnish basic information for the design and operating procedure of water-gas generators.

The apparatus designed for this work has been described.99/ 1/ The results show that for electrode carbon in the temperature range 850° to 950° C. a saturation pressure of about 800mm. of mercury exists. The use of higher steam pressures does not increase the rate of gasification.

Development Work on the Fischer-Tropsch Process

Equipment has been installed at the Central Experiment Station, Bureau of Mines, Pittsburgh, Pa., for chemical-engineering development work on the synthesis of liquid fuels by the catalytic hydrogenation of carbon monoxide.

98/ Warner, B. R., Mechanism of the Steam-Carbon Reaction: Jour. Am. Chem. Soc., vol. 65, 1943, pp. 1447-1451.

99/ Warner, B. R., An Improved Pressure-Regulating Device: Ind. Eng. Chem., anal. ed., vol. 15, 1943, pp. 637-638.

1/ Warner, B. R., Pressure Dependence of the Rate of Gasification of Carbon: Jour. Am. Chem. Soc., vol. 66, 1944, pp. 1305-1309.

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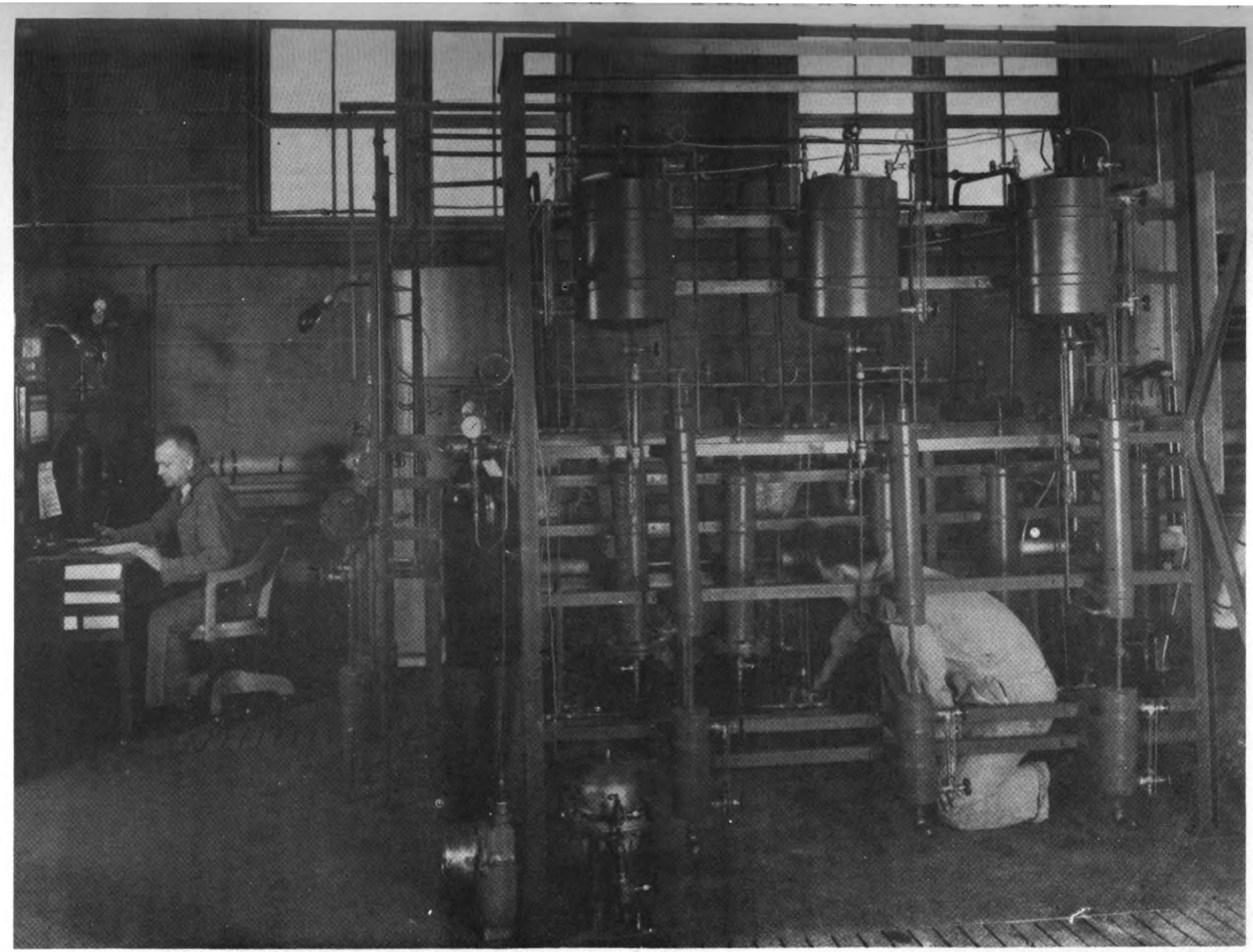

FIGURE 12.- Three-stage experimental Fischer-Tropsch unit.

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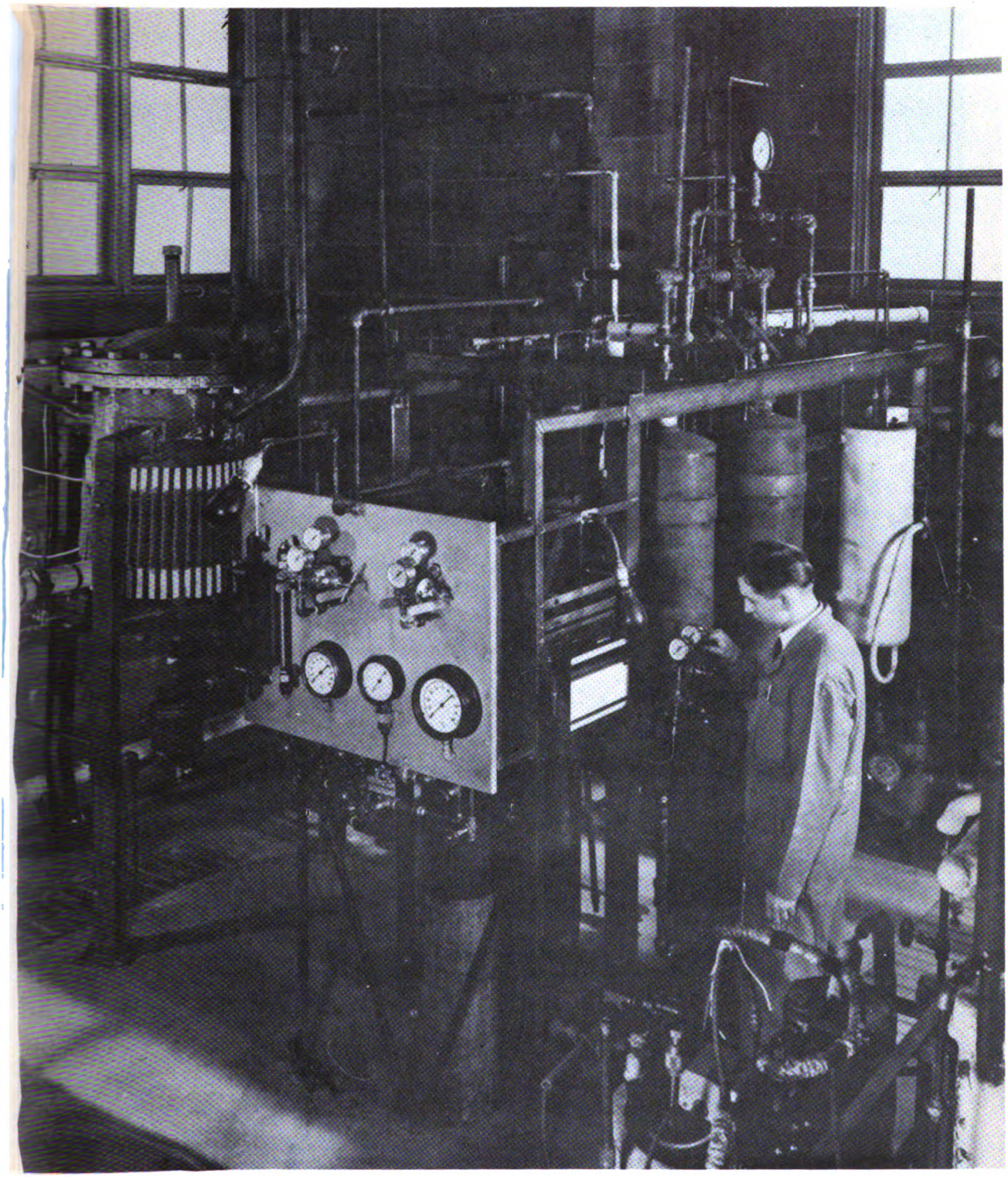

FIGURE 13.- Single-stage Fischer-Tropsch unit.

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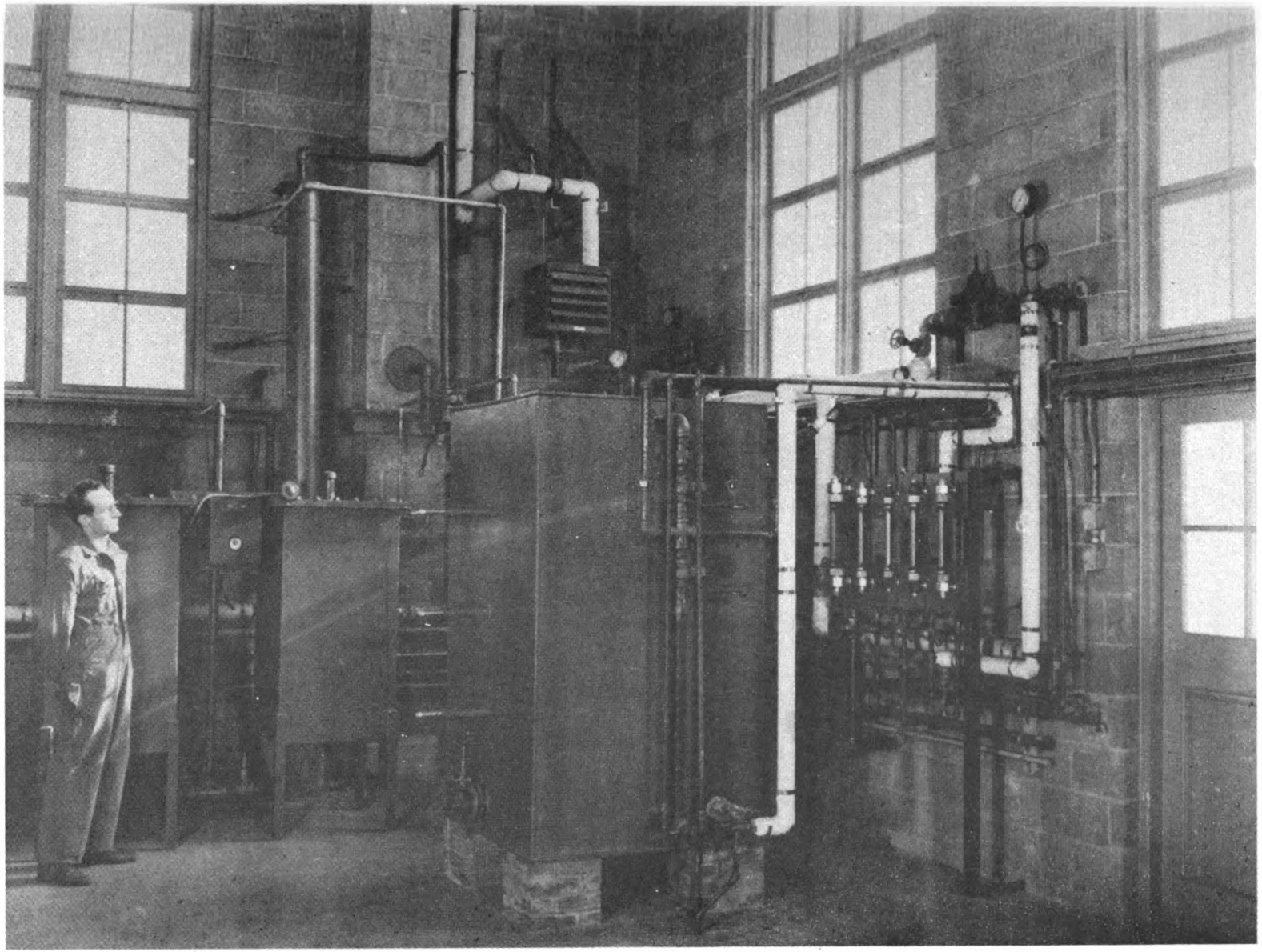

FIGURE 14.- Synthesis-gas generator.

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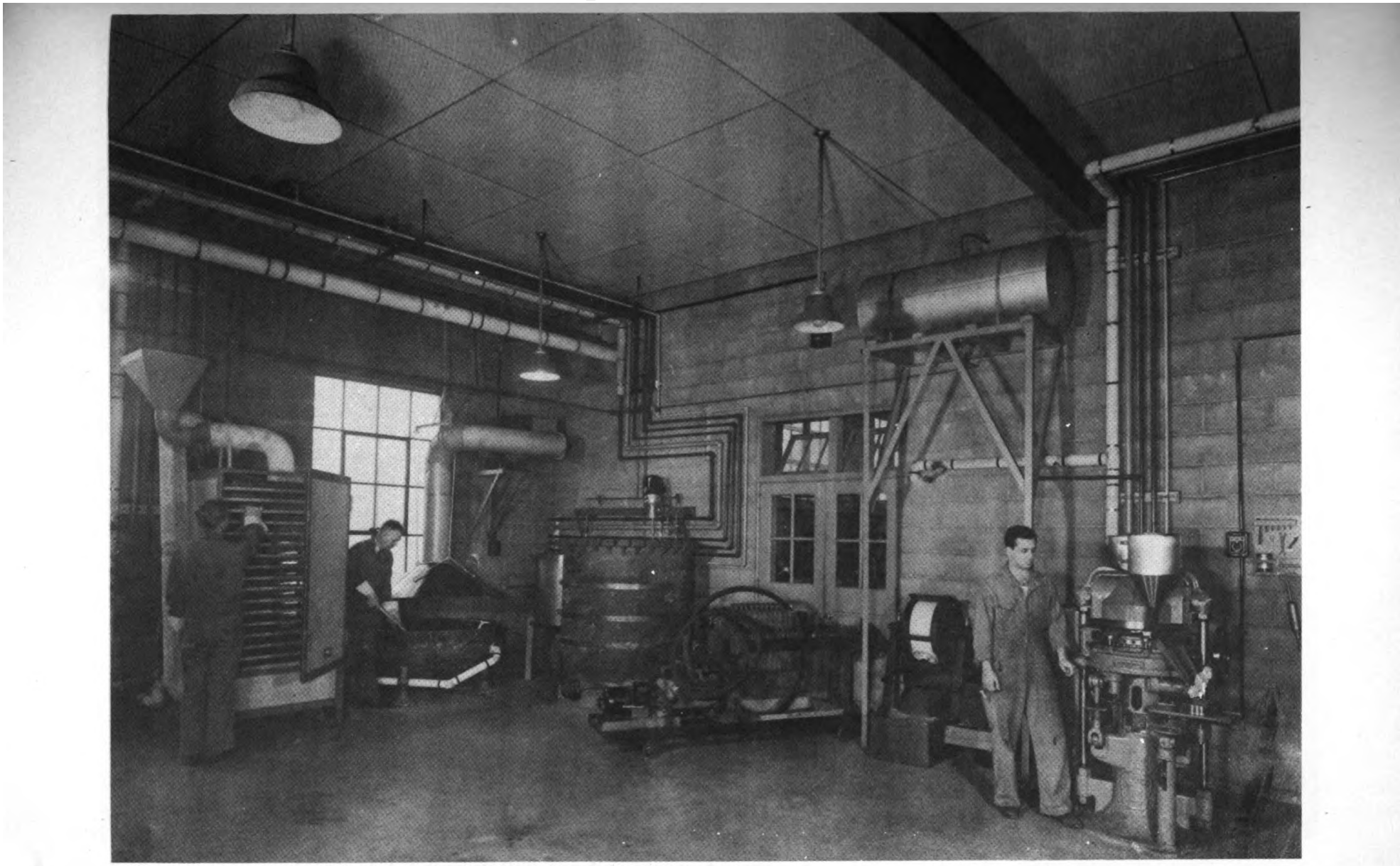

FIGURE 15.- Catalyst-preparation equipment.

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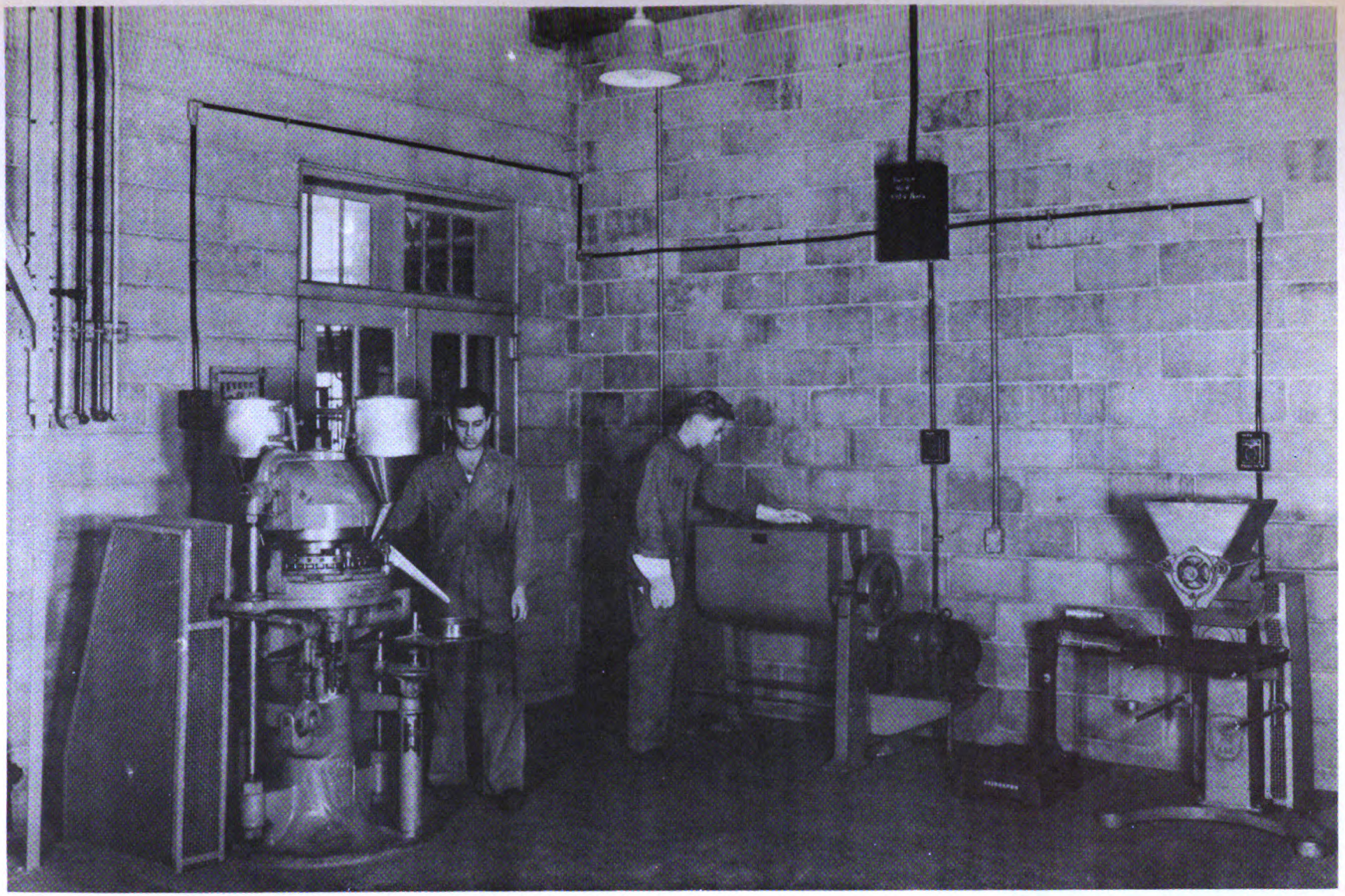

FIGURE 16.- Pelleting machine and granulators.

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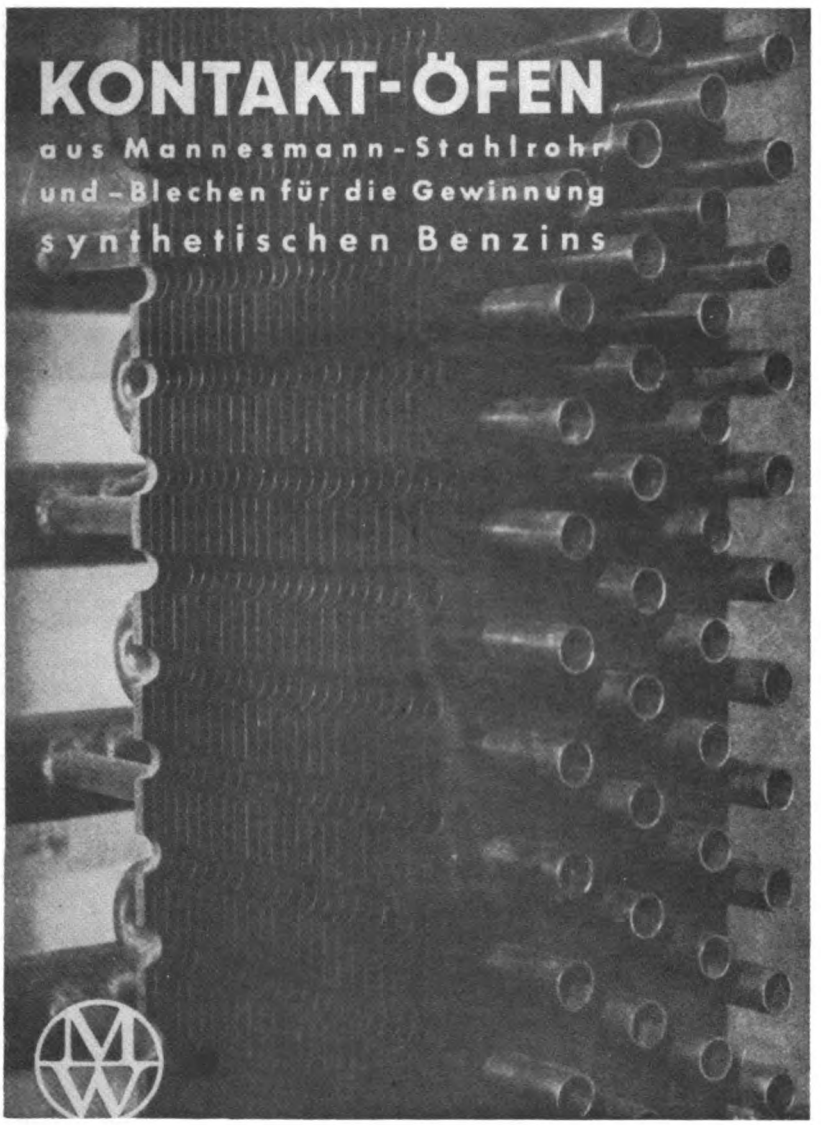

FIGURE 17.- Ruhrchemie Fischer-Tropsch converter.

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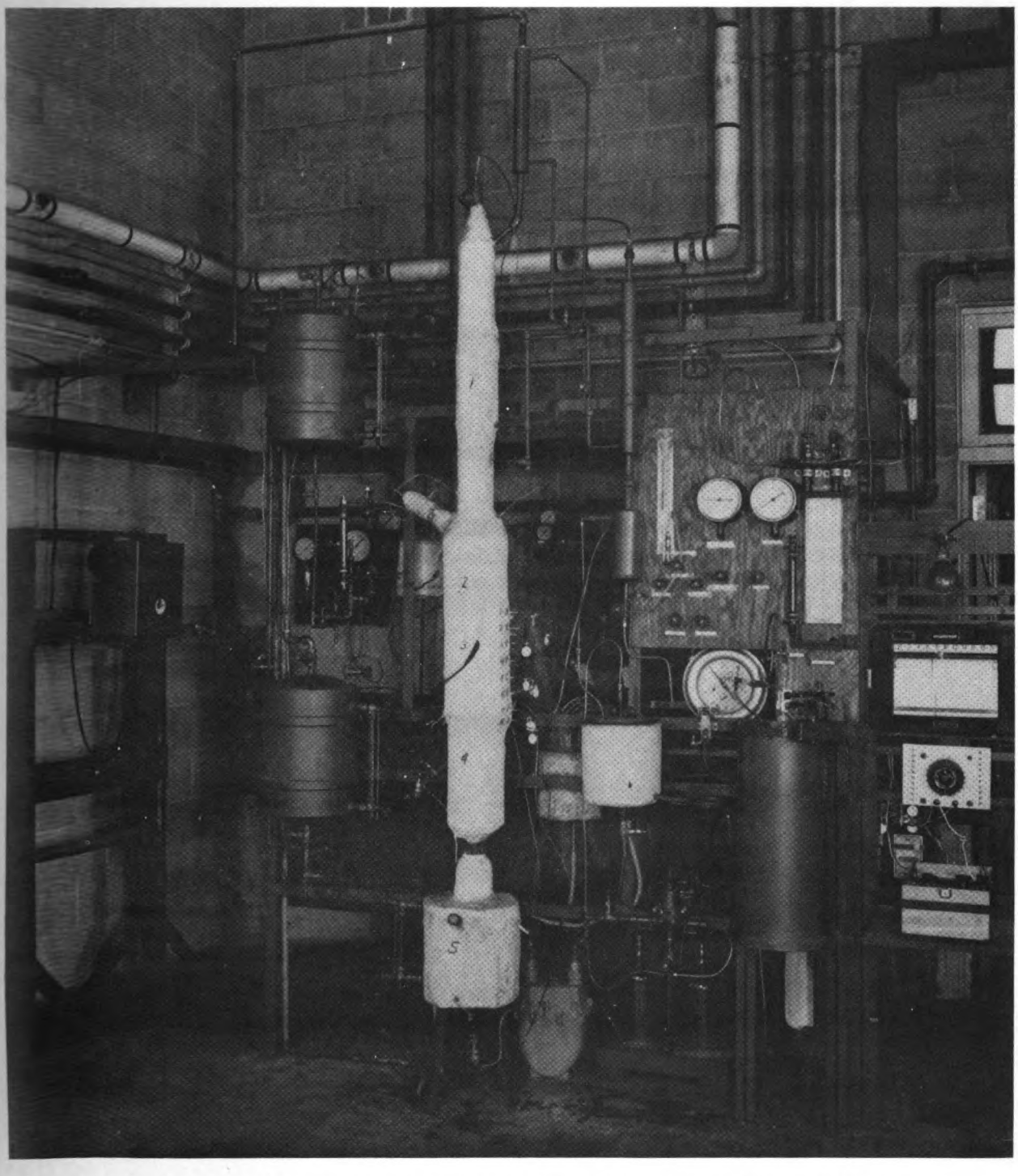

FIGURE 18.- Internally cooled experimental converter.

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Figure 12 is a view of a three-stage experimental unit in which the liquid products from each stage can be condensed before the remaining gas is passed to the next stage. This plant will produce about 0.5 liter of liquid product per 24 hours. Figure 13 shows a single-stage unit with a capacity of about 3 gallons of liquid product per 24 hours. In figure 14 the synthesis gas generator is the large, rectangular chamber in the foreground. This steel box is lined with firebrick and contains a bed of nickel-alundum catalyst through which a mixture of oxygen, steam, and natural gas is passed. The resulting mixture of carbon monoxide and hydrogen is passed through a sulfur-removal system, part of which consists of the two smaller steel chambers in the background of figure 14.

Figure 15 is a picture of the catalyst-preparation equipment, showing the precipitation tank in the far corner of the room. To the right of this tank is a filter press and to its left a tray drier. Along the wall to the right of the filter press are a ball mill and pellet-making machine. A distilled water tank is supported on a steel frame above the ball mill. Figure 16 shows a closer view of the pelleting machine with a mixer and granulator to the right. The capacity of the catalyst-preparation plant is about 20 pounds of the finished catalyst per 24 hours.

Because the hydrogenation of carbon monoxide to produce liquid hydrocarbons is a highly exothermic reaction, and because of the narrow temperature range of efficient operation, the heat-transfer problem has been of great importance in the design of the Fischer-Tropsch converters. The type of converter used in most of the Ruhrchemie plants is illustrated in figure 17. The catalyst is packed in narrow spaces between steel sheets through which cooling tubes are interlaced. Water under pressure is circulated through the tubes. The cost of this converter is relatively high because the design necessitates large amounts of steel per unit of oil produced. Various ways have been suggested for removing the heat of reaction and controlling the reaction temperature. One of the most promising of these consists in flushing a cooling oil of proper boiling range over the catalyst particles, the heat of vaporization of this oil being supplied by the heat of the synthesis reaction. To test this procedure, the equipment of the type illustrated in figure 18 has been assembled and the temperature gradients and catalyst activities measured. Tests have been conducted with 1/2-, 1-1/2-, and 3-inch tubes, a catalyst bed about 12 inches deep, and the cooling oil condensed and returned by gravity flow to the catalyst bed. It has been found possible to maintain virtually completely adiabatic conditions in the converter, and precise temperature control has been readily obtained. Using a cobalt-thoria-magnesia-kieselguhr catalyst, at 75 to 100 pounds per square inch pressure of $2H_2+1CO$ gas, the yield of oil thus far has been about 75 percent of that obtained using the same catalyst in a Runhrchemie converter.

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